



METROPOLITAN  
TRANSPORTATION  
COMMISSION

# **IntelliDrive<sup>SM</sup> Technologies to Support HOT Lane Operations**

**A White Paper**

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**with**

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# 1 EXECUTIVE SUMMARY

This white paper is prepared for the Metropolitan Transportation Commission (MTC), the transportation planning, coordinating and financing agency for the nine-county San Francisco Bay Area. MTC plans to analyze and test the feasibility and potential value of using IntelliDrive technologies to support high occupancy toll (HOT) and express lane operations.

The overall project will be divided into two phases. Phase 1 covers the preparation of this white paper. Phase 2 will comprise a demonstration of IntelliDrive technologies to support operations on a selected express lane facility in the Bay Area. The purpose of this white paper is to identify specific concepts that are feasible for, and would benefit from, field testing of HOT lane operations using IntelliDrive technologies.

## *A National Perspective on HOT Lane Operations and Challenges*

HOT lanes are a special type of managed lane where high-occupancy vehicles (HOVs) are allowed access to the lane at no cost, while low-occupant vehicles (LOVs) must pay a toll to access the lane. In general, HOT lanes become an option when the capacity of the managed lane is underutilized by HOVs alone, and a higher level-of-service can be provided in the managed lane compared to the adjacent general purpose lanes to those drivers who are willing to pay. The higher level-of-service in the managed lane is maintained primarily by adjusting the pricing for LOVs.

HOT lanes are being implemented or considered in locations across the United States. IntelliDrive systems and technologies may be able to help address issues that have been identified by practitioners and researchers at the national level, including:

- Enforcement of HOT lane payments and vehicle occupancy requirements;
- Communication of traveler information;
- Monitoring of traffic demand and facility performance; and
- Monitoring of safety conditions.

## *Overview of Bay Area Express Lane Operations and Challenges*

The vision in the nine-county Bay Area is an 800-mile network of express lanes that includes 500 miles of converted HOV lanes and 300 miles of new lanes that close gaps on the existing HOV network. In general, the operational features of the express lane network are as follows:

- The predominant roadway design is one express lane in each direction;
- Separation between the express lane and adjacent general purpose lane is a double yellow line, with no physical barrier;
- Midpoint access locations vary with travel demand, but average 4 to 5-mile intervals;

- Electronic toll collection technology is based on FasTrak, which is currently used on the eight Bay Area toll bridges. FasTrak uses 915 MHz and is governed by California Title 21;
- Tolling zones will be equipped with cameras that provide license plate recognition to support the enforcement of toll evasion;
- A dynamically-priced toll structure will be used, charged per mile;
- HOVs (2+ or 3+, depending on corridor) will travel toll free;
- The California Highway Patrol (CHP) will provide enforcement of occupancy and buffer zone violations, monitoring HOT lanes from the inside shoulder and pulling-over violators on the outside shoulder.

Interviews with express lane stakeholders in the Bay Area identified a set of challenges for which IntelliDrive-based solutions could be sought. These include:

- Access between the general purpose lanes and the express lane;
- Toll evasion enforcement;
- Enforcement of occupancy and buffer zone violations;
- Back-office toll processing;
- Provision of traveler information to express lane users.

### ***Status of IntelliDrive<sup>SM</sup> Programs***

The integration of information from vehicles and the roadway infrastructure to facilitate the management and operations of the transportation system is a long-standing vision. In 2004, U.S. DOT, the American Association of State Highway and Transportation Officials (AASHTO), state and local transportation agencies, automotive manufacturers, and others came together to develop a vehicle-infrastructure integration (VII) initiative.

Communications between the vehicles and roadside, and from vehicle to vehicle, were a key component of VII. In 1999 the Federal Communications Commission (FCC) set aside spectrum in the 5.9 GHz band for DSRC (dedicated short-range communications), that would be capable of providing secure, high-capacity, low-latency data communications for a range of applications. More recently, the VII initiative has evolved into the IntelliDrive program, which is generally descriptive of capabilities rather than particular solutions, and expands on earlier VII efforts to be more inclusive of alternative technical approaches.

### ***IntelliDrive Technologies and Protocols***

**Communications technologies** are fundamental to the design and deployment of IntelliDrive systems. Each technology has its own strengths and limitations, and the choice of which technology to use in a particular application has significant consequences for functional capability, performance, and reliability. Technologies that have the potential to support IntelliDrive systems for HOT lane operations include:

- Radio Frequency Identification (particularly systems operating at 915 MHz that form the basis of current FasTrak electronic toll collection in the Bay Area);
- 5.9 GHz DSRC;
- 3G Cellular;
- WiMAX; and
- Wi-Fi.

The selection of the communication technology is dependent upon the specific use case and is discussed in detail in the section: Analysis of Use Cases for Express Lane Operations.

Other important enabling technologies include:

- **Positioning systems** – a central component of many IntelliDrive applications. It is desirable to provide a system that can provide lane-level positioning accuracy; generally defined as a 95 percent Circular Error Probability (CEP) of less than 1m.

Most positioning system solutions incorporate GPS in some form. Differential GPS (DGPS) can increase positional accuracy by supplementing the information from the satellite network with position information from fixed, ground-based reference stations. Carrier Phase DGPS, an approach used in high-accuracy surveying equipment can further improve positional accuracy. Positional accuracy for moving vehicles can be further enhanced through the combination of appropriate GPS solutions with inertial navigation systems (INS).

Recommendations for additional GPS research testing are included in Section 11.1.

- **Bluetooth** – a wireless communications protocol for short-range data exchange between devices, originally designed to be used in place of cabled connections. The technology has been implemented in a wide variety of applications, including the collection of vehicle probe data.

### *Use cases for Express Lane Operations*

A series of use cases of IntelliDrive technologies for the deployment and operations of express lanes in the Bay Area have been identified and analyzed. These use cases include:

- Toll collection;
- Dynamic pricing;
- In-vehicle account management;
- Back-office toll processing;
- Vehicle occupancy;
- Automated enforcement;
- Probe vehicles;
- Traveler information; and

- Regional and corridor traffic management.

In addition, other key technical and operational issues that may affect the successful implementation of the use cases have been assessed. These issues include:

- Lane-by-lane vehicle detection;
- In-vehicle driver displays; and
- Driver and vehicle privacy.

Based on these analyses, selected use cases are recommended for proposed Phase 2 field testing. The recommended use cases are those that appear to have the greatest potential to satisfy criteria that are included in the following list:

- The use case emphasizes one or more IntelliDrive technologies that can support the operational needs of the express lanes in the Bay Area;
- The use case holds the promise to solve a major challenge identified by a stakeholder;
- The use case is technically feasible in the relatively near-term;
- The use case offers the potential to offer a significant advance from the current state of the practice in either technology application or express lane operations.

### *Phase 2 Recommended Use Cases*

Three use cases are recommended for the Phase 2 field tests. These use cases are described in Section 11 of this white paper and comprise the following:

- **Recommended Use Case # 1 – Toll Collection:**

This use case will include assessment of 5.9 GHz DSRC installed in different overhead and roadside equipment configurations, as well as the evaluation of dual mode 5.9 GHz/915 MHz equipment. The use case will also include an assessment of the capabilities of high-accuracy vehicle positioning systems that would supplement toll collection applications, and future buffer zone violation enforcement.

- **Recommended Use Case # 2 – Back-Office Toll Processing:**

This use case will comprise a pilot test that demonstrates the ability to process toll transactions using credit and/or debit cards. The use case will demonstrate the ability of driver to provide credit card details through their in-vehicle equipment and secure communication of the information using DSRC. The use case will include the use of contactless credit or debit cards with an onboard proximity reader, as well as the ability for drivers to input credit card details through an in-vehicle keypad or touch screen associated with an onboard IntelliDrive device.

- **Recommended Use Case # 3 – Traveler Information:**

This use case will comprise several aspects of traveler information uniquely associated with express lane operations or facilitated by the

availability of IntelliDrive technologies. The use case will address the provision of relevant information to the express lane user or potential user.

The use case will evaluate the ability to pass dynamic pricing information and FasTrak account balance information into the vehicle in real-time using an appropriate communications channel, including DSRC and 3G wireless. The use case will also include a travel time information component comprising three elements: the collection of probe data from vehicles; the processing of data into reliable travel time information; and the dissemination of that information back to the vehicle. Vehicles equipped with 5.9 GHz DSRC, 915 MHz toll tags or Bluetooth devices will be able to provide probe data for comparative analysis of travel times in general purpose lanes versus express lanes. The development of appropriate data analysis techniques should also be undertaken and validated. Finally, the use of alternative communications paths, including DSRC and 3G, to the vehicle for the dissemination of travel time information should be assessed.

### *Analysis of Potential Express Lane Corridors*

In general, based only on the timing of implementation, two corridors are candidates for the demonstration phase: the I-880/SR 237 Express Lane Connector, and the I-680 Express Lane Corridor.

The **I-680 Express Lane Corridor** is located on a 14-mile section of southbound I-680 between SR 84 and SR 237. Approximately 80 percent of the facility is located in Alameda County, with the remainder in Santa Clara County. HOVs will use the express lane for free, while LOVs will pay a toll. Toll rates will be set dynamically to maintain free-flow conditions on the express lanes.

The express lanes will use transition lanes for access, and solid lines as a buffer zone between the express lanes and the general purpose lanes. This facility will include three entrance points to the express lanes, and three exit points. Motorists will receive express lane toll pricing information from overhead changeable message signs in advance of the express lane. All LOVs that wish to use the express lanes will be equipped with a FasTrak toll tag, while HOVs will need to cover their toll tag before entering the express lane to prevent a toll charge. A toll transaction will be initiated when a LOV vehicle enters the express lane; processing of the toll is a back office function that will use existing systems.

The length, configuration, and availability of roadside and overhead infrastructure appear to make the I-680 Express Lane a more desirable location for testing; thus, it is recommended for the Phase 2 demonstration.

### *Analysis of Fleet Options*

Testing of the IntelliDrive express lane use cases in Phase 2 will require the availability of test fleets. Specific requirements for the test fleets, including requirements relating to individual vehicles and drivers, should be developed as part of the development of demonstration evaluation and test plans. The number of vehicles needed for testing a particular use case, for example, will generally be

determined by the statistical confidence and accuracy desired for the resulting performance measurements. Fleet and driver requirements are discussed for each recommended use case in the Phase 2 Recommendation section.

## **2 INTRODUCTION AND OBJECTIVES**

This white paper is prepared for the Metropolitan Transportation Commission (MTC). MTC is the transportation planning, coordinating and financing agency for the nine-county San Francisco Bay Area. MTC manages a range of technology projects intended to improve transportation system management in the region, including having an active role in the national IntelliDrive<sup>SM</sup> program.

In addition, the Commissioners of MTC serve as the Bay Area Toll Authority (BATA), a separate public agency formed by the California Legislature in 1997, with responsibilities that include administration of all Bay Area toll revenue and joint oversight of the toll bridge construction program with Caltrans and the California Transportation Commission. In April 2009, MTC adopted the long-range *Transportation 2035 Plan*, which commits to developing an 800-mile express lane network throughout the region.

A grant received through the Urban Partnership Program (UPP), sponsored by the U.S. Department of Transportation (U.S. DOT), offers MTC the opportunity to implement a pilot program to demonstrate the advanced technology capabilities of IntelliDrive to improve travel demand strategies. MTC plans to analyze and test the feasibility and potential value of using IntelliDrive technologies to support high occupancy toll (HOT) and express lane operations.

The overall project will be divided into two phases. Phase 1 covers the preparation of this white paper, which will be presented by MTC at a national workshop in October 2009. Phase 2 will comprise a demonstration of IntelliDrive technologies to support operations on a selected express lane facility in the Bay Area.

The purpose of this white paper is to identify specific concepts that are feasible for, and would benefit from, field testing of HOT lane operations using IntelliDrive technologies. This white paper identifies opportunities and challenges associated with IntelliDrive technologies and applications that could support HOT lane operations. The paper provides recommendations on specific components of an IntelliDrive HOT lane project that can be demonstrated during Phase 2.

## **3 A NATIONAL PERSPECTIVE ON HOT LANE OPERATIONS AND CHALLENGES**

HOT lanes are a special type of managed lane where high-occupancy vehicles (HOVs) are allowed access to the lane at no cost, while low-occupant vehicles (LOVs) must pay a toll or user fee to access the lane. In general, HOT lanes become an option when the capacity of the managed lane is underutilized by HOVs alone, and a higher level-of-service can be provided in the managed lane

compared to the adjacent general purpose lanes to those drivers who are willing to pay. The higher level-of-service in the managed lane is maintained primarily by adjusting the pricing for LOVs.

HOT lanes are being implemented or considered in locations across the United States. HOT lanes present their own set of technical, institutional, design and operational challenges compared to conventional lanes or other types of managed lanes. One purpose of this white paper is to consider how IntelliDrive systems and technologies can help address or mitigate the issues that have been identified by practitioners and researchers at the national level.

Key topics that are critical to proper HOT lane operation and which may be amenable to IntelliDrive solutions include:

- Enforcement of HOT lane payments and vehicle occupancy requirements;
- Communication of traveler information;
- Monitoring of traffic demand and facility performance; and
- Monitoring of safety conditions.

### ***3.1 Enforcement of HOT lane payments and vehicle occupancy requirements***

HOT lane enforcement typically addresses a set of potential violations beyond those that are common to any other traffic lane. These enforcement activities can present major institutional, safety, and technological challenges. Enforcement of toll evasion, where a vehicle that is required to pay a toll in order to use the facility fails to do so, is frequently automated on conventional toll facilities. While similar technological solutions can be considered on HOT lane facilities, different implementation approaches may be needed to address the mix of free HOVs and toll-paying LOVs using the lane.

However, other violations such as occupancy verification and buffer zone violations currently require a physical police presence to be effective. Occupancy enforcement requires a visual inspection of the number of occupants, often in a fast moving vehicle during periods of high demand and perhaps from a location where a law enforcement officer has only limited visibility into the vehicle.

Technological solutions are therefore being pursued to support these efforts. At a national level, topics that are receiving significant attention include:

- The ability to accurately monitor vehicle position to identify buffer violations;
- The development of roadside imaging techniques to assist law enforcement in targeting occupancy violations;
- Research and development of approaches for vehicle occupancy counting in conjunction with advanced airbag systems.

### **3.2 *Communication of traveler information***

The additional signing needs for HOT lanes can compound an already difficult and constrained freeway design and operating environment. Drivers who may consider using the HOT lanes generally want to know:

- The rules and regulations of the HOT lanes, which may change by time-of-day;
- Toll price;
- Where access points (both ingress and egress) are located;
- Whether there is an incident ahead, and whether it is affecting the HOT lane, general purpose lanes, or both;
- Whether there are other events or situations causing changes in the HOT lane operating conditions; and
- What travel time benefits they will achieve by using the HOT lane rather than the general purpose lanes.

The challenges are compounded in a regional network of HOT lanes where it is desirable to provide a seamless travel experience over the entire network to the driver. However, longer trip lengths can potentially create the need for pricing changes en-route to maintain HOT lane performance. Similarly, individual HOT lanes within the network can have significantly different pricing. Therefore, it is important to ask what user information can be shifted from the roadside signage into the vehicle to address driver needs and facility performance.

### **3.3 *Monitoring traffic demand and facility performance***

Although changes in pricing can be used to deter traffic demand for free-flow operation of the managed lane, there are unanswered questions about the effects of HOT lanes on overall traffic demand on a particular roadway, and the ability to maintain reliable roadway operations at these potentially higher levels of vehicle throughput. Other systems or technologies, in addition to variable pricing, may be required to monitor, manage, and operate a facility comprising both managed lanes and general purpose lanes to maximize vehicle throughput as the facilities mature and demand grows over time.

Topics in roadway facility management and operations to be examined include:

- The ability to monitor dynamic roadway conditions and make changes to pricing and/or HOT lane rules prior to the onset of congestion to ensure free-flow operation and trip reliability in the HOT lane;
- The ability to monitor the dynamic roadway environment under changing conditions and to effectively communicate these conditions to commuters, which may affect mode or route choice, rather than just a driver's decision to use a HOT lane or not;
- Testing and development of an array of traffic management strategies, while taking a holistic view of operations for the complete roadway environment; for a corridor; or for an entire regional transportation network.

### **3.4 Safety in constrained cross-sections**

Early HOT lane projects tended to be barrier-separated facilities with limited access opportunities. This design approach helped simplify pricing strategies, enforcement, and driver information requirements. Today, however, many projects are being implemented that are not barrier-separated due to cross-section constraints and may have multiple access locations. Lane encroachment from the general purpose lanes into the HOT lanes in buffer-separated situations is a significant safety concern, particularly where the overall roadway cross-sections are physically constrained.

Questions therefore exist about how to address these safety issues. HOT lane design topics that are currently receiving attention include:

- Examining whether new systems and technologies can help provide flexibility in future lane designs;
- Techniques that will improve safety due to the speed differential between managed lanes and general purpose lanes;
- Creating alternative access designs to meet specific needs and conditions;
- Examining the improvements in safety for various lane, shoulder, and buffer width configurations.

### **3.5 Further background information on HOT lane issues**

Beyond these key topics, other HOT lane issues that are receiving attention at the national level include:

**Equity and fairness** - Equity issues have been raised on practically every HOT lane project and have also played a role in HOV lane projects, since the application of lane management techniques inevitably restricts some users either modally or spatially. Various approaches are being used as a component of the roll-out of HOT lane facilities, including expanded rideshare and transit options and transit credit programs. Experience from new programs will continue to shed light on public response to pricing. However, equity in various forms will undoubtedly be a real and perceived issue that deserves research and monitoring as part of any new HOT lane project.

**Forecasting demand** - It is difficult to accurately forecast demand. Demand for HOT lanes is highly discretionary because a free option is both available and very visible on the adjacent roadway. The advent of micro-simulation and mesoscopic simulation sketch planning tools and the restructuring of regional models have helped provide a means to test pricing strategies for new HOT lanes. However, more real project experience will be valuable for assessing and calibrating available and emerging forecasting and operational assessment tools.

**Environmental benefits** - The limited quantitative research that has been conducted with respect to the air quality benefits of HOV and HOT facilities has been inconclusive. Given the growing interest in climate change and assessing the transportation strategies that will have a positive impact on reducing greenhouse

gas emissions, there will be a need to more closely examine the emissions benefits associated with HOT lanes. For example, can systems be used to regulate speed through pricing and other mechanisms in a manner that will minimize greenhouse gas emissions from vehicles?

## **4 OVERVIEW OF BAY AREA EXPRESS LANE OPERATIONS AND CHALLENGES**

The vision in the nine-county Bay Area is an 800-mile network of express lanes that includes 500 miles of converted HOV lanes and 300 miles of new lanes that close gaps on the existing HOV network. This proposed network is illustrated in Figure 1. The legislative framework for the Bay Area Express Lane Network is available at: [http://www.mtc.ca.gov/legislation/HOT\\_LegislativeFramework.pdf](http://www.mtc.ca.gov/legislation/HOT_LegislativeFramework.pdf). The plan calls for implementation of the system over the next ten years with a goal of seamless travel throughout the region. The development and implementation of the Bay Area Express Lane Network has five primary objectives:

- More effectively manage the region's freeways in order to provide higher vehicle and passenger throughput and reduce delays for all travelers in the corridor, especially those traveling by carpool, vanpool or bus, within each travel corridor.
- Provide an efficient, effective, consistent, and seamless system for customers of the network.
- Provide benefits to travelers within each corridor commensurate with the revenues collected in that corridor, including expanded travel options and funding to support non-highway options that enhance effectiveness and throughput.
- Expedite the implementation of the network using a rapid delivery approach that, to the greatest extent possible, recognizing safety, operational, and environmental constraints, relies upon existing highway right of way and minimizes the environmental impact.
- Use express lane toll revenue to finance construction of the network and other corridor improvements, operate and maintain the network; and provide transit services and improvements in the network corridors.

The regional express lane network will be authorized through AB 744, a bill that at the time of writing is moving through the legislative process. This legislation will authorize the Bay Area Toll Authority (BATA), an agency affiliated with MTC that administers revenue from seven toll bridges in the region, to develop, operate, and maintain the express lane network. A Bay Area Express Lane Network Project Oversight Committee (BAY POC), comprising representatives from BATA, California Department of Transportation (Caltrans), the California



In general, the operational features of the Bay Area Express Lane Network are as follows:

- The predominant roadway design is one express lane in each direction;
- Separation between the express lane and adjacent general purpose lane is a double yellow line, with no physical barrier;
- Midpoint access locations vary with travel demand, but average 4 to 5-mile intervals;
- Electronic toll collection technology is based on FasTrak, which is currently used on the eight Bay Area toll bridges. FasTrak uses 915 MHz and is governed by California Title 21;
- Tolling zones will be equipped with cameras that provide license plate recognition to support the enforcement of toll evasion;
- A dynamically-priced toll structure will be used, charged per mile;
- HOVs (2+ or 3+, depending on corridor) will travel toll free;
- The California Highway Patrol (CHP) will provide enforcement of occupancy and buffer zone violations, monitoring HOT lanes from the inside shoulder and pulling-over violators on the outside shoulder.

#### ***4.1 Express Lane Challenges in the Bay Area***

This section briefly describes specific express lane challenges in the Bay Area that were identified by stakeholders during interviews conducted in July and September 2009<sup>1</sup>. The stakeholders represent various agencies involved in the development of HOT lane projects in the Bay Area: BATA; California Highway Patrol; Caltrans; Gray-Bowen and Co., Inc. for Alameda County Congestion Management Agency; MTC; and, Santa Clara Valley Transportation Authority (VTA).

For the purpose of general prioritization, the challenges are categorized as either “primary” (issues raised by multiple interviewees and emphasized during the discussion), or “secondary” (issues raised by one or more interviewee and generally perceived as less critical than primary challenges). The discussion that follows provides an overview of the challenges identified, and the questions posed concerning the possible role of IntelliDrive technologies in addressing the challenges.

##### **4.1.1 Primary Challenges**

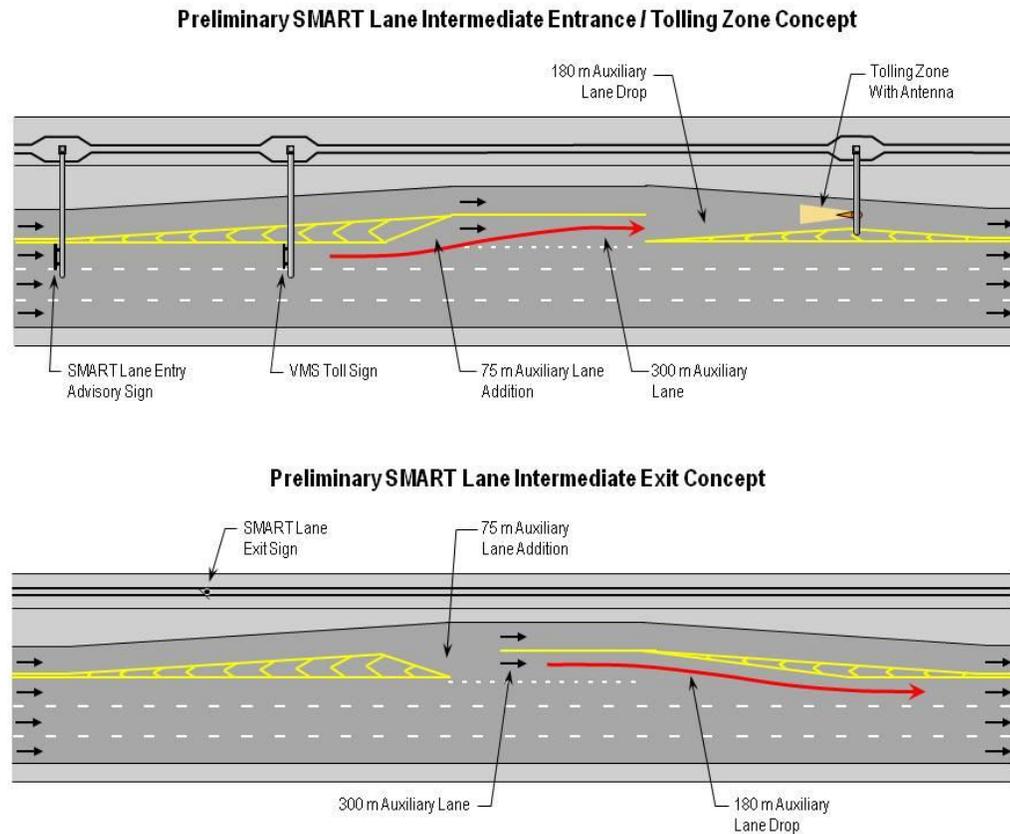
###### ***Access***

The design of access at intermediate points along the length of an express lane was a topic identified and discussed during all stakeholder interviews. There are multiple access configurations under consideration for the system. The project

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<sup>1</sup> Individuals who participated in the stakeholder interviews are identified in Appendix A.

that is furthest in development and under construction is along southbound I-680 between SR 84 and SR 237 in Alameda and Santa Clara counties. This project will use a *transition lane* approach as illustrated in Figure 2. This design separates entering and exiting vehicles into distinct ingress and egress access points, with each access point providing an auxiliary weave lane. This option is unique to the I-680 project.



**Figure 2: HOT Lane Entrance and Exit Concepts<sup>2</sup>**

Other facilities are considering two alternative designs: *limited weave zone access*, which is a skip-stripe opening in the double solid stripe that is of sufficient length to allow both entering and exiting vehicles to maneuver; or *continuous access*, which is the prevailing skip-striping design for existing HOV lanes in the Bay Area that allows access at any point along the lane. Limited access design is the approach with the greatest level of “on-the-ground” experience in HOT lane operations in other cities.

There is a preference among some stakeholders to retain the current continuous access design used in existing HOV lanes and apply it to the new express lanes in

<sup>2</sup> “Southbound I-680 Smart Carpool Lane Concept of Operations,” prepared for Alameda County Congestion Management Agency by Wilbur Smith Associates, March 2006.

the region, but current technological limitations related to tolling and enforcement make this approach impractical over long corridors. A white paper developed for BATA explores in detail the potential use of continuous access in terms of operational performance, design requirements, toll system requirements, and enforcement needs<sup>3</sup>.

Based on the information gathered during the interviews, a set of questions were formulated:

- What role can IntelliDrive technologies play in addressing the performance and safety issues of continuous access design?
- Is there an IntelliDrive application that can determine vehicle position to differentiate usage between an express lane and the adjacent general purpose lane with sufficient accuracy to effectively assess a toll?
- Can such an application be used to discourage “gaming” the system, where users might weave in or out of the express lane at freeway bottlenecks or tolling points?
- Could IntelliDrive systems address these challenges more effectively than current technologies?

These questions help drive the technology assessments in Section 6, and have influenced the definition and recommendation of use cases in Section 7 of this white paper.

### ***Toll Evasion Enforcement***

Toll evasion enforcement emerged as an issue with multiple stakeholders. Current published information indicates that LOVs will require a FasTrak toll tag in order to use an express lane. HOVs, however, will need to place their toll tag in the supplied Mylar bag to avoid a toll charge as they pass through an express lane tolling zone.

This approach presents challenges for enforcing toll violations. If a LOV enters an express lane without a toll tag and is caught by the CHP, the CHP will issue a court citation for an occupancy violation. CHP has noted that even LOVs with a valid toll tag that is misread by the tolling infrastructure may be issued a court citation for occupancy violation, since the CHP prefers not to enforce toll violations. However, all violators and tag misreads that are not caught by the CHP equate to lost revenue if there is no backup to the toll tag reader. Furthermore, a system that allows a higher ratio of missed tolls may lead to more violators trying to game the system.

To reduce violation rates and revenue leakage, a license plate recognition system can be used as a backup to the toll tag reader. This requires a way for the toll system to distinguish HOVs from LOVs, since the distinction cannot be made

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<sup>3</sup> “An Assessment of Continuous Express Lane Access,” prepared for Bay Area Toll Authority (BATA) by Parsons Brinckerhoff, May 2009.

from the license plate images alone. On the toll bridges and SR91, vehicles segregate into HOV and LOV lanes. Since the footprint of the regional network is too constrained to fit an HOV and an LOV lane in each toll zone, the vehicle must be able to relay its occupancy to the tolling system. One solution is to equip all vehicles with occupancy self-declaration toll tags, whereby drivers can toggle a switch to the setting that matches their vehicle occupancy.

Self-declared LOVs are then charged the express lane toll; self-declared HOVs are not charged a toll; and non-equipped vehicles are subject to automated toll violation enforcement via license plate imaging. Vehicles that self-declare as HOVs are subject to additional visual enforcement as described below.

Based on the stakeholder interviews, the following questions were formulated:

- What role could IntelliDrive play in the evolution toward a fully automated system for enforcing toll evasion?
- What role could IntelliDrive play in the vehicle ‘self-declaring’ whether it is a LOV or HOV?
- Could an IntelliDrive system perform this function more effectively than other system alternatives?

#### ***Enforcement of Vehicle Occupancy and Buffer Zone Violations***

The enforcement activities that will be performed by CHP were discussed by most stakeholders. CHP is responsible for the enforcement of occupancy violations, as well as moving violations, and mechanical violations, on the express lanes. Prosecution of these violations requires in-person action and issuance of a citation by a CHP officer. CHP does not enforce toll violations, which are enforced through license plate recognition on existing FasTrak toll facilities, and may require the use of this technology combined with occupancy self-declaration tags on HOT lanes, as described above.

The occupancy self-declaration toll tag would automate the toll evasion process allowing it to proceed in a similar manner to toll violation enforcement on conventional FasTrak toll facilities. However, to support the visual occupancy enforcement of self-declared HOVs by CHP, the switchable toll tag would be used to trigger a visual signal at each toll zone. A series of lights on a roadway structure will indicate to an officer stationed near a toll zone whether the driver has self-declared as an HOV or SOV. The officer can then make a visual check of the vehicle and determine whether a self-declared HOV does indeed have multiple occupants in the vehicle. Suspected violators can then be pursued by the officer.

CHP personnel indicate that even though this process may be happening at full highway speeds, it will quickly become routine to officers.

Based on the information gathered during the interviews, the following questions were formulated:

- What role could IntelliDrive play in the evolution toward a fully automated system for enforcing occupancy and buffer zone violations?
- In particular, can IntelliDrive technologies provide lane level detection that would support enforcement of buffer zone violations, as well as other applications including toll collection and discrimination of vehicles between express lanes and adjacent general purpose lanes?
- What are the prospects for using onboard occupancy data associated with advanced airbag systems to provide accurate counts of occupants so tolls can be charged accordingly?
- Can occupancy counting systems that may be available in the near-term, such as roadside multi-band near-infrared systems<sup>4</sup>, be integrated with IntelliDrive technologies to provide a tool that assists CHP in targeting likely violators?

### ***Back-Office Toll Processing***

It was noted that the existing 915 MHz RFID-based FasTrak system provides a perfectly acceptable means of collecting tolls in the Bay Area. It was also recognized that the use of IntelliDrive technologies, such as 5.9 GHz DSRC, may be beneficial for the more challenging set of toll collection needs in the express lane environment. However, there may not be sufficient incentive for broader change from 915 MHz to DSRC for all toll collection in the region.

Back-office administration for the FasTrak system, including issuing transponders, administering customer accounts, and the collection and processing of toll revenues, is a significant effort for BATA. A long-term goal would allow BATA to minimize or eliminate its role in the transponder and toll processing business.

Based on this discussion, the following questions were formulated:

- What role could IntelliDrive technologies play in supporting BATA's back-office toll processing functions?
- In particular, can IntelliDrive technologies facilitate the payment of tolls through direct, real-time interaction between vehicles and the networks of the major financial institutions, such as credit card companies?

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<sup>4</sup> See V. Goodin, J. Wikander, et.al. *Automated Vehicle Occupancy Verification Technologies*. White Paper for the HOV Pooled Fund Study. Federal Highway Administration. Report FHWA-HOP-07-132. August 2007: "The main potential benefit offered by infrared systems is the ability to operate in darkness as well as daylight. Infrared systems operating in certain wavelengths can utilize camera illumination that is outside the visible light range and that consequently would minimize driver distraction. The primary developmental thrust for roadside infrared occupancy detection systems has focused on near infrared (NIR) systems, which detect the reflection of shorter infrared wavelengths from objects illuminated by a NIR source. The NIR band is more suitable for occupancy verification purposes, as it is not as readily blocked by vehicle glass or window tint. "

## 4.1.2 Secondary Challenges

### *Driver Information*

Fixed signing currently proposed for implementation on express lanes, before the entrance points, will convey information on the variable toll rates for trips to two exit points along the facility. Stakeholders felt that this was sufficient for the initial express lane corridors. However, there were several concerns raised about the ability to effectively communicate the information that drivers would be seeking over a sizable network of express lanes. In addition to price for their specific, intended exit point, drivers may also seek comparative travel times.

Given the physical and practical limitations of providing all forms of individualized driver information on signage within the driving environment, the question was raised as to whether IntelliDrive technologies could support tailored trip information for the user. There was also a suggestion that the information used by a driver for trip planning purposes could be made available to modeling applications to forecast conditions on the network.

### *Throughput Optimization*

A number of issues were raised regarding the long-term efficiency of the freeway system as a whole, and the limitations of the express lane network to support forecast demand. HOV demand in some corridors may necessitate a 3+ restriction at the outset; while other facilities may experience growth in HOV demand that will require a modification of HOV occupancy requirements over time.

With current and future limitations in right-of-way and funding, there was discussion that presented a view of freeway lane operations from a holistic perspective, effectively allowing for managed use of all lanes. If this philosophy was to be supported as regional policy, could IntelliDrive technologies facilitate lane tolling at the precision required allowing all freeway lanes to be managed by time-of-day?

### *Tolling and Integrated Payment*

Stakeholders recognized that the legacy FasTrak toll system in the region is effective at performing current toll collection functions. However, the question was raised whether IntelliDrive applications could facilitate integrated fare payment and trip credits across multiple modes. It was asked whether IntelliDrive technologies could support a universal payment mechanism.

### *Transit*

Transit is an important component of the express lane network concept in the Bay Area. There is a desire to demonstrate transit benefits to increase transit use and address equity concerns. It was asked if IntelliDrive technologies could support functions to achieve these objectives, including integrated payment and reliable traveler information.

## 5 STATUS OF INTELLIDRIVE<sup>SM</sup> PROGRAMS

This section provides a background discussion of the national IntelliDrive program, including the SafeTrip-21 initiative.

### 5.1 *Background of IntelliDrive Program*

The integration of information from vehicles and the roadway infrastructure to facilitate the management and operations of the transportation system is a long-standing vision. The establishment of standard roadway signs and signals provided a capable and trustworthy solution for many years. Increasing congestion and limited resources, however, led to the conceptualization and development of intelligent transportation systems (ITS) and, in the first years of this century, to vehicle infrastructure integration (VII). The U.S. DOT, the American Association of State Highway and Transportation Officials (AASHTO), state and local transportation agencies, automotive manufacturers, ITS America and others came together in 2004 to plan, research, and develop the vehicle, roadway, and information systems that would be needed to achieve the vision for VII.

Communications between the vehicles and roadside, and from vehicle to vehicle, were a key component of the VII architecture. This need had been recognized in the 1990s, and in 1999 the Federal Communications Commission (FCC) set aside spectrum in the 5.9 GHz band for DSRC (dedicated short-range communications). DSRC, as conceived, would be capable of providing secure, high-capacity, low-latency data communications for a range of applications directed at improving safety, alleviating congestion, and providing traveler information. Standardization of DSRC protocols and messaging, and applications built on those standards, became the focus of much of the early VII development.

U.S. DOT and its partners initiated several related programs to research and develop VII capabilities. The most comprehensive program established a cooperative agreement between U.S. DOT and the Vehicle Infrastructure Integration Consortium (VIIC) to build and test a VII Proof-of-Concept (POC) using DSRC. The POC developed onboard and roadside DSRC equipment, established a backhaul network infrastructure for management and data communications, and demonstrated various safety, mobility, and commercial VII applications, including probe data gathering, toll collection, and provision of in-vehicle traveler information. The demonstrations were not without challenges, however. Findings from the VII POC left open questions on many issues, including the need for improved positional accuracy from GPS (the Global Positioning System), the reliability of some DSRC connections, the complexity of security and privacy-protection schemes, and collection of probe data from vehicles.

Subsequently, U.S. DOT initiated the SafeTrip-21 program to accelerate the process of applying alternative market-ready solutions to the challenges of integrating vehicles and infrastructure. The California Connected Traveler Field Test Bed was established under SafeTrip-21 in the San Francisco Bay Area in

2008 as one of two sites for demonstration of these types of solutions. Several applications are being demonstrated within the California Test Bed, addressing the provision of multi-modal traveler information, probe data gathering, transit parking information, work zone management, and signalized intersection delay monitoring. Unlike the VII POC, GPS-enabled mobile phones using 3G communications provided both probe data and user interfaces for many of the applications demonstrated in California.

## 5.2 The IntelliDrive Program Today

U.S. DOT's IntelliDrive<sup>SM</sup> program provides a conceptual framework for relating these programs, technologies, and the resultant knowledge base. The program (more fully described at its web site, [www.intelldrivusa.org](http://www.intelldrivusa.org)) addresses policy and technology issues, as well as provides a context for further development. The IntelliDrive program is generally descriptive of capabilities rather than particular solutions, and expands on earlier VII efforts to be more inclusive of alternative technical approaches. The key concept in this approach is the "open platform" for technologies, in which the IntelliDrive subsystems are defined by their capabilities and interfaces rather than their particular technological implementations. The need to have vehicles communicate wirelessly with infrastructure, for example, can be met by DSRC *or* 3G cellular *or* radio frequency identification (RFID) *or* other technologies, depending on the particular requirements of those communications.

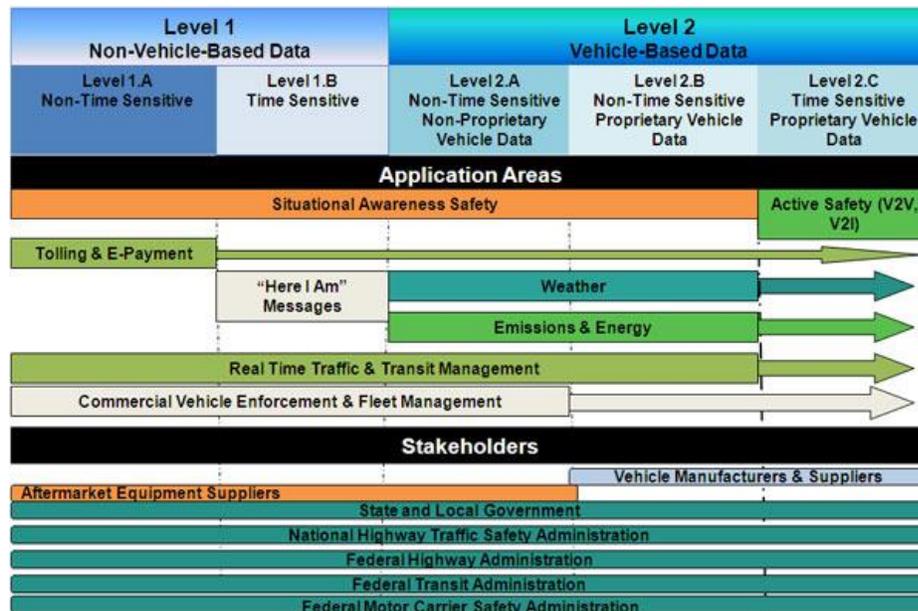


Figure 3: IntelliDrive Development  
 (Ref: <http://www.intelldrivusa.org>)

Figure 3, as presented on the IntelliDrive web site, illustrates the relationships between technological capabilities, IntelliDrive applications, and stakeholders. The technical aspects are distinguished by their interfaces and capabilities—

vehicle-based or non-vehicle-based, time sensitive or not, proprietary vehicle data or not. Applications are staged roughly according to the amount of data and complexity of the interfaces needed to facilitate those applications. Stakeholders then relate to the technical needs and interfaces.

Tolling and e-payments, which can be considered to include many of the key attributes of a HOT lane application, occupy a “Level 1.A” position in this scheme of development for IntelliDrive applications. While these applications provide tangible demonstration of IntelliDrive benefits, they do not require many of the more complex technical capabilities needed in later applications. As described in the text that accompanies the above figure, Level 1.A applications “do not require vehicle-based data” and can use “multiple communications technologies.” These attributes provide considerable latitude in the design of IntelliDrive-compatible tolling applications.

## **6 INTELLIDRIVE TECHNOLOGIES AND PROTOCOLS**

This section provides a discussion of the potential communications protocols that may be suitable for supporting IntelliDrive applications appropriate for express lane operations. The section concludes with a review of what is currently known about the plans of toll equipment and other vendors to develop 5.9 GHz DSRC devices.

### **6.1 *Scan of Communications Technologies for Express Lane Operations***

Communications technologies are fundamental to the design and deployment of IntelliDrive systems. Each technology has its own strengths and limitations, and the choice of which technology to use in a particular application has significant consequences for functional capability, performance, and reliability.

#### **6.1.1 RFID**

RFID technologies, particularly those operating at 915 MHz, have become the most generally-accepted communication solutions for electronic toll collection in the U.S. These solutions can be implemented using a simple systems architecture and are direct to purpose—they provide unique identification and other descriptive attributes for vehicles as they pass detectors along a tolled roadway. General standards for RFID data specifications and interfaces exist, but can allow for a wide variety of implementations.

##### ***Technological strengths***

- Proven technical solution;
- Established vendor base;
- Acceptable provisioning and operational costs.

##### ***Limitations***

- Multiple implementations; no uniform standards;
- Low data bandwidth;

- Short-range communications.

#### ***Demonstrations***

- Established market presence and acceptance among toll agencies and concessionaires;
- Numerous deployments in tolling, including both local and regional systems.

#### ***Potential Applications***

- Vehicle identification in tolling;
- Point-to-point probe vehicle travel times;
- Lane-level detection by installing antennas above each lane and using an algorithm to identify straddling vehicles.

### **6.1.2 5.9 GHz DSRC**

DSRC solutions have had a strong association with IntelliDrive and its VII predecessor. In its most recent form, DSRC has become synonymous with wireless communications in a reserved 5.9 GHz frequency band for the Wireless Access in a Vehicular Environment (WAVE) protocol. Standards for 5.9 GHz DSRC (including IEEE 1609 for WAVE and SAE J2735 for DSRC message sets) have been drafted and continue to be developed as the technology acquires momentum from demonstrations by multiple vendors and agencies.

#### ***Technological strengths***

- Designed specifically for vehicular environments;
- Builds on prior 802.11 wireless communications standards;
- High bandwidth;
- Built for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications;
- Low latency;
- Secure data transmissions enhanced by short-range communications.

#### ***Limitations***

- Still in development; no large-scale deployment tests; no U.S. production deployments;
- Demonstration tests to date have left unresolved technical issues including:
  - Message prioritization between safety, mobility and convenience applications is still being resolved;
  - Incomplete hand-offs in overlapping roadside equipment coverage can result in lost messages;
  - Probe data protocols require significant tuning to particular applications;
  - Complex security management.

### ***Demonstrations***

- VII Proof-of-Concept demonstrations (Michigan Development Test Environment (DTE)) (2008);
- CICAS-V demonstrations (California DTE) (2008);
- VII tolling application test (Dumbarton Bridge, California) (September 2008);
- OmniAir-Brisa E470 demonstration (Denver, CO) (July 2009).

### ***Potential Applications***

- Vehicle identification and roadside exchange of transaction data in tolling;
- Roadside exchange of data for dynamic pricing;
- Roadside exchange of data for in-vehicle account management;
- Point-to-point probe vehicle travel times and roadside collection of probe data;
- Roadside exchange of traveler information;
- Secure roadside exchange of data for financial transactions in back-office systems;
- Lane-level detection (with additional research and development).

## **6.1.3 3G Cellular**

Third-generation (3G) wireless communications provide wide-area voice and data services through a single set of standards and infrastructure. The 3G protocols are documented in the International Mobile Telecommunications-2000 (IMT-2000) standards and include a variety of technologies in wide deployment around the world.

### ***Technological strengths***

- Established technology with multiple vendors and service providers;
- Almost ubiquitous U.S. coverage;
- Good data bandwidth;
- Wide-area coverage;
- Cellular approach designed for secure data transmissions.

### ***Limitations***

- Network latencies and relative unreliability make it inappropriate for real-time V2V and V2I safety applications;
- Location and localization accuracy are generally not adequate for lane-level matching.

### ***Demonstrations***

- Used for backhaul purposes in the VII California Test Bed;
- Used in SafeTrip-21 California Connected Traveler Field Test Bed Mobile Millennium project;
- Demonstrated for backhaul purposes as part of VII POC in Michigan DTE;

- Ford/Microsoft Sync;
- OnStar.

#### ***Potential Applications***

- Exchange of transaction data in tolling;
- Exchange of data for dynamic pricing;
- Exchange of data for in-vehicle account management;
- Collection of probe data;
- Exchange of traveler information;
- Secure exchange of data for financial transactions in back-office systems.

### **6.1.4 WiMAX**

WiMAX is a relatively new wireless technology designed to provide high-bandwidth data communications over a wide (or even metropolitan) area. The WiMAX standards (IEEE 802.16) support both fixed and mobile implementations.

#### ***Technological strengths***

- Long range (three to ten miles);
- High bandwidth;
- Established standards.

#### ***Limitations***

- Limited distribution of third-party services; custom installation is expensive;
- Unknown network latencies;
- Localization not demonstrated; probably use GPS-derived location.

#### ***Demonstrations***

- Available as commercial networking service in limited markets;
- Demonstrated for backhaul purposes as part of the VII POC in Michigan DTE.

#### ***Potential Applications***

Assuming that WiMAX service is available, it would facilitate the same applications as indicated for 3G cellular communications.

- Exchange of transaction data in tolling;
- Exchange of data for dynamic pricing;
- Exchange of data for in-vehicle account management;
- Collection of probe data;
- Exchange of traveler information.

### **6.1.5 Wi-Fi**

The Wi-Fi family of technologies provides wireless communications for local area networks. Wi-Fi networking equipment is widely available and used in

home, commercial, and industrial applications to reduce reliance on hardwired local networks. The Wi-Fi protocols themselves are described by the IEEE 802.11 standards.

***Technological strengths***

- Vast number of commercial off-the-shelf products in a wide variety of configurations;
- Inexpensive to deploy;
- Adequate bandwidth for HOT lane applications;
- Localization capability has been demonstrated in non-vehicular context.

***Limitations***

- Unproven in HOT lane applications;
- Not specifically designed for mobile environments.

***Demonstrations***

- Wi-Fi connections from vehicles-to-roadside collectors have been used in IntelliDrive probe data collection schemes in Oakland County, Michigan;
- Wi-Fi asset tagging is available from several vendors and could be adapted to tolling.

***Potential Applications***

Although Wi-Fi might be adaptable to some tolling-related applications, more appropriate communications technologies are available for each such application.

## **6.1.6 LTE**

Long-Term Evolution (LTE) is a next-generation (4G) mobile communications technology currently in development. It will compete in many respects with WiMAX.

***Technological strengths***

- High bandwidth;
- Increased cell spacing.

***Limitations***

- Still in commercial vendor trials;
- No commercial products or services likely until 2011 at the earliest.

***Demonstrations***

- No end-user demonstrations currently available;
- Expected to operate much like current generation of 3G cellular services.

***Potential Applications***

- LTE communications could facilitate the same applications as indicated for 3G cellular communications at such time as LTE becomes commercially available.

## **6.2 Scan of Enabling Technologies for Express Lane Operations**

### **6.2.1 Positioning Systems**

Positioning systems are a central component of many IntelliDrive applications. For these applications, it is desirable to provide a system that can provide lane-level positioning accuracy; generally defined as a 95 percent Circular Error Probability (CEP) of less than 1 meter (m).

Most positioning system solutions incorporate GPS in some form. The use of differential GPS (DGPS) can increase positional accuracy by supplementing the positional information from the satellite network with position information from fixed, ground-based reference stations. A nationwide network of DGPS stations (the NDGPS) is operated by the U.S. Coast Guard (authority that was originally granted to them by the U.S. Department of Transportation prior to the agency's transfer to the Department of Homeland Security). The accuracy of NDGPS is reported to be 65 cm at 100 km from the reference station.

Carrier Phase DGPS, an approach used in high-accuracy surveying equipment can further improve positional accuracy; even to a 20-30 cm 95% CEP. However, this is achieved at a significantly higher equipment cost at the present time. Positional accuracy for moving vehicles can be further enhanced through the combination of appropriate GPS solutions with inertial navigation systems (INS) and distance measurements from pulsed wheel sensors. INS devices use onboard computers linked to motion sensors (accelerometers) and rotation sensors (gyroscopes) to calculate the current position, orientation, and velocity of the vehicle using dead reckoning.

Two recent assessments of positioning system accuracy are of particular relevance to this white paper.

#### ***VII Proof-of-Concept (POC) Positioning System Tests***

A series of positioning system tests were performed by the VIIC during the POC. This included a test to determine if a 95% CEP of less than 1 m could be achieved using two low-cost commercial GPS systems onboard the test vehicles. The test vehicles were operated on a test track; straight and slalom courses on a closed facility; and on the open highway. Positioning data collected by each vehicle's onboard equipment was compared with data from a survey grade positioning system that provided ground truth. The two commercial GPS systems used in the test are not identified in the project report<sup>5</sup>.

Test results show that neither GPS receiver was able to meet the desired 1m 95% CEP accuracy: one device achieving a 95% CEP of 6.13 m, and the second achieving a 95% CEP of about 10 m. Analysis of the results indicates that greater accuracy was achieved when vehicles are traveling on straight sections of road, but positional accuracy deteriorated when the vehicle experienced rapid changes in direction in either latitude or longitude. The report suggests that there is

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<sup>5</sup> U.S. DOT Research and Innovative Technologies Administration, "VII Proof of Concept Results and Findings Summary – Vehicle. Final Report." Prepared by the VII Consortium, May 2009.

potential to solve this issue using filters that treat latitude and longitude measures together as a coupled pair of functions rather than independently. Additional testing using High-Accuracy NDGPS corrections did not substantially improve positional accuracy for either receiver.

### ***Caltrans Testing of Carrier Phase DGPS aided INS***

Caltrans has funded work by the Department of Electrical Engineering at the University of California, Riverside to develop a roadway relative position determination system for snow plows. The system must be capable of maintaining vehicle position to an accuracy within a few centimeters. The system developed comprises an INS aided by Carrier Phase DGPS. The system has been successfully tested on a section of I-80 near Donner Pass in the northern Sierra Nevada, which has challenges to accuracy related to terrain and vegetation.<sup>6</sup>

As noted earlier, equipment costs for Carrier Phase DGPS are relatively high compared to other solutions at the present time. Caltrans estimates costs to be around \$25,000 for each base station (which must maintain line-of-sight with the equipped vehicles), and \$20,000 for each on-vehicle receiver. While this would not be practical for a large scale IntelliDrive deployment in the near-term, there may be value in limited testing of the technology during the Phase 2 demonstration.

## **6.2.2 Bluetooth**

Bluetooth<sup>TM</sup> is a wireless communications protocol for short-range data exchange between devices, originally designed to be used in place of cabled connections. The technology has been implemented in a wide variety of personal communications and computing devices; from mobile phones and headsets to computers and printers. The Bluetooth specifications, available at [www.bluetooth.com](http://www.bluetooth.com), have been developed and maintained by the Bluetooth Special Interest Group.

### ***Technological strengths***

- Established technology with multiple vendors;
- Simple, inexpensive technology;
- Established standards;
- Designed for mobile, discoverable connections.

### ***Limitations***

- Limited range (up to 100 meters);
- Demonstrated only for basic traffic data collection.

### ***Demonstrations***

- TrafficCast BlueTOAD;
- Traffax BluFax.

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<sup>6</sup> Farrell, Jay A., "Carrier Phase Differential GPS aided INS for Snowplow Guidance," Caltrans Project: 65A0178, Final Report, (undated).

### *Potential Applications*

- Vehicle identification in tolling, particularly when coupled with other communications services to be provided by 3G cellular or WiMAX;
- Point-to-point probe vehicle travel times;
- Lane-level detection (with additional research and development).

## **6.3 Scan of Vendors**

This section presents a scan of system and equipment vendors in technological areas applicable to an IntelliDrive-based HOT lane demonstration. This white paper does not endorse any specific vendor products. It is also acknowledged that the product field is constantly evolving, and new products not referenced here may become available. The material in this section is intended to confirm that products exist to support a viable demonstration.

### **6.3.1 Potential Vendors for Dual Mode 915 MHz RFID and 5.9 GHz DSRC Tolling Systems**

#### *Kapsch*

- Established tolling products widely used in Europe;
- Purchase of DSRC products from TechnoCom Corporations in August 2008 provided entry to U.S. IntelliDrive market;
- Recently issued press release on dual mode 5.9 GHz/915 MHz demonstration on Colorado's E-470<sup>7</sup>.

#### *MARK IV*

- Widely deployed 915 MHz RFID tolling solutions used in E-ZPass systems throughout the northeastern U.S.;
- Announced successful testing of dual mode JANUS tolling reader in September 2008;

#### *TransCore*

- One of the four original 2005 DSRC development partners (with Sirit, Raytheon, and Mark IV);
- Announced availability of dual mode 5.9 GHz/915 MHz Encompass solution in 2005;
- Have published papers stating expectation that DSRC for tolling applications is not yet ready for deployment<sup>[1]</sup>. The gist of the concern is that DSRC technology is not mature enough compared to existing 915 MHz solutions to scale to current tolling deployment needs.<sup>8,9</sup>

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<sup>7</sup> Kapsch TrafficCom AG, [http://www.kapsch.net/en/ktc/press/articles/files/PA\\_KTC\\_5.9-GHz\\_tolling\\_technology\\_at\\_the\\_Trial\\_Facility\\_in\\_Denver\\_Colorado\\_EN.pdf](http://www.kapsch.net/en/ktc/press/articles/files/PA_KTC_5.9-GHz_tolling_technology_at_the_Trial_Facility_in_Denver_Colorado_EN.pdf) (accessed September 30, 2009)

<sup>[1]</sup> Schnacke, Dick. *Colliding Gracefully*. TollTrans 2005.

<http://www.transcore.com/newsroom/pdf/TollTrans%20Schnacke.pdf> (accessed August 7, 2009).

<sup>8</sup> Gravelle, Kelly. A Sticking Point? TollTrans 2007. <http://www.transcore.com/pdf/tolltrans2007.pdf> (accessed September 30, 2009).

### ***Raytheon***

- One of the original 2005 DSRC development partners;
- Awarded Florida turnpike contract in 2006, but did not implement DSRC;
- Participated in VII POC development;
- Have not announced any commercial DSRC-based tolling system.

### ***Sirit***

- One of the original 2005 DSRC development partners;
- Have 5.9 GHz DSRC sniffer product for analysis and verification of DSRC data packets;
- Have not announced any commercial DSRC-based tolling system.

### ***Savari***

- Have multifunction communications components for both vehicle and roadside; cover both 915 MHz RFID and 5.9 GHz DSRC;
- Represent their vehicle and roadside components as a platform for E-payment applications, but have not announced any commercial DSRC-based tolling system.

## **6.3.2 Possible Vendors for Positioning Systems**

There are multiple vendors offering an enormous variety of GPS products and integrated system solutions that could be explored for a Phase 2 demonstration. These providers include Leica, NovAtel, Trimble, and Raytheon. The wide range of product offerings makes it difficult to recommend a shortlist of candidate vendors.

The report on the positioning system testing at the VII POC does not identify the GPS system providers. Caltrans has identified NovAtel as their provider of Carrier Phase DGPS equipment for their roadway relative position determination system testing.

## **6.3.3 Possible Vendors for Bluetooth Technology**

### ***Traffax BluFax***

- Senses passing Bluetooth transceivers as the basis for collecting traffic data (for example, travel times)<sup>10</sup>;
- Based on technology developed at the University of Maryland<sup>11</sup>;
- Used as part of the validation of the I-95 Corridor Coalition's vehicle probe project and in other traffic studies;
- No specific information on applications in tolling products.

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<sup>9</sup> TC IP, Ltd. *Achieving National Toll System Compatibility – It Isn't Rocket Science*.  
<http://www.transcore.com/pdf/Interoperability-White-Paper-2009.pdf> (accessed September 30, 2009).

<sup>10</sup> <http://www.traffaxinc.com/>

<sup>11</sup> University of Maryland – Center for Advance Transportation Technology, *Bluetooth Monitoring Technology Concept of Operation & Deployment Guidelines*, [www.catt.umd.edu/documents/UMD-BT-Brochure\\_REV3.pdf](http://www.catt.umd.edu/documents/UMD-BT-Brochure_REV3.pdf) (accessed October 7, 2009).

### *TrafficCast BlueTOAD<sup>TM</sup>*

- Senses passing Bluetooth transceivers as the basis for collecting traffic data (for example, travel times)<sup>12</sup>;
- Incorporates wireless mesh networking and cellular data packet backhaul for traffic monitoring;
- Provides data integration with TrafficCast's Dynaflow 2.0 predictive traffic information product;
- No specific information on applications in tolling products.

## **7 ANALYSIS OF USE CASES FOR EXPRESS LANE OPERATIONS**

This section identifies use cases of IntelliDrive technologies for the deployment and operations of express lanes in the Bay Area. Opportunities for using IntelliDrive technologies, as well as potential challenges, are identified and recommendations are provided. The recommendations include identification of specific wireless communication technologies and any other technologies needed for successful demonstration of the use case.

Selected use cases are recommended for proposed Phase 2 field testing. The recommended use cases are those that appear to have the greatest potential to satisfy criteria that are included in the following list:

- The use case emphasizes one or more IntelliDrive technologies that can support the operational needs of the express lanes in the Bay Area;
- The use case holds the promise to solve a major challenge identified by a stakeholder;
- The use case is technically feasible in the relatively near-term;
- The use case offers the potential to offer a significant advance from the current state of the practice in either technology application or express lane operations.

### **7.1.1 Toll Collection**

Tolling has been considered an IntelliDrive use case since the beginning of the national VII program. At that time, 5.9 GHz DSRC was the core communications medium, and this technology remains well-suited to the low latency, secure transactions that characterize toll collection.

An essential component of any express lane implementation is the ability to collect tolls from LOVs that elect to use the express lane, while providing free access to the lane for those vehicles that meet the high occupancy criterion. It appears that viable toll collection solutions have been identified for the initial Bay Area express lane implementations by leveraging existing FasTrak systems and using either new switchable, occupancy self-declaration toll tags in all vehicles, or

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<sup>12</sup> TrafficCast International, Inc., *TrafficCast's BlueTOAD<sup>TM</sup> to Monitor Traffic Using Bluetooth*, <http://trafficcast.com/news/article/132/> (accessed October 7, 2009).

by requiring HOV users to remove and protect their toll tag to avoid a charge at an express lane tolling zone.

However, there appear to be potential advantages to developing a demonstration that includes toll collection based on 5.9 GHz DSRC equipment. In general, a demonstration of DSRC-based toll collection in the Bay Area will help advance the state of knowledge relating to this technology, building on the recent tests conducted on the E-470 toll facility in Denver. Any assessment of toll collection using DSRC during the demonstration should consider both the development of appropriate interfaces to the existing FasTrak systems, including the use of current back-office systems, and the ability to minimize or eliminate BATA's toll processing responsibilities in the back-office as described in Section 7.1.4 below. As discussed below, there are several technical challenges with any toll collection technology that can be explored in more detail as part of the demonstration. In addition, the use of DSRC appears to open up opportunities to address other operational needs that are unique to express lane implementations.

### ***Opportunities***

Kapsch has reported that its DSRC technology can achieve very high read rates (significantly higher than those typically reported for toll operations in California using 915 MHz devices). The company reports that its system collected 100% of more than 10,500 DSRC sample passes using a fleet of 27 vehicles<sup>13</sup>.

Kapsch has also reported that its DSRC product can accurately locate a device-equipped vehicle within a specific traffic lane without any additional in-vehicle equipment, such as GPS. This approach could minimize the highway infrastructure needed to prevent cross-lane reads in the type of open highway situation where HOT lanes will run adjacent to general purpose.

TransCore and Kapsch have reported efforts to create "dual-mode" 915 MHz/5.9 GHz readers and tags. The availability of products with this capability could help address concerns regarding the significant existing investment in 915 MHz technology for FasTrak in California.

A practical consideration for BATA is the cost of replacing existing 915 MHz FasTrak transponders every five to seven years when the battery fails. There may be an opportunity to deploy IntelliDrive technologies onboard the vehicle that draw power from the vehicle itself, thus avoiding this recurring expense.

### ***Challenges***

Results from independent testing of the ability to "localize" the reads of DSRC in-vehicle devices within a lane without additional in-vehicle equipment or a multi-lane roadway infrastructure are not yet available from Kapsch.

There is enormous investment in the Bay Area in 915 MHz equipment for toll collection. While the implementation of HOT lanes provides an opportunity to

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<sup>13</sup> "Kapsch report accuracy of 100% in electronic toll tests with 5.9GHz - SwRI tests," Toll Roads News, posted 29 October 2008, <http://www.tollroadsnews.com/node/3804>.

require users to obtain an alternative technology, a broader transition plan would be needed to switch all toll collection equipment to the new technology.

At the present time, it is believed that only 915 MHz RFID and 5.9 GHz DSRC are sufficiently well-developed and tested to be considered viable for toll collection using vehicle-to-infrastructure communications. A recent report indicates that GPS-based technologies are being considered as a potential technological solution to aggregate miles driven for direct mileage-based road user charging<sup>14</sup>. It is assumed, however, that such an approach would still require a communications path between the vehicle and the roadside, such as that provided by DSRC or 3G.

### ***Recommendation***

Toll collection is a viable use case for the Phase 2 field test.

Possible test scenarios for Phase 2 include the following:

- Use of 5.9 GHz DSRC equipment mounted on the existing overhead structures, over the express lane alone, to determine the ability of the technology to differentiate vehicle location in a multi-lane situation. This test should be configured in a manner that explores the possibility of reliable toll collection in a roadway layout that provides continuous access to the express lane;
- Use of dual-mode 5.9 GHz/915 MHz readers and tags with the 5.9 GHz/915 MHz equipment mounted on the existing overhead structure alongside the existing 915 MHz equipment to evaluate the effectiveness of the dual-mode technology and its compatibility with existing FasTrak operations.
- Use of 5.9 GHz DSRC equipment mounted on the side of the road, potentially in conjunction with high-accuracy positioning equipment onboard the vehicle, to evaluate the capability of lane level detection without the need for an overhead structure, and the capability for toll collection.

### **7.1.2 Dynamic Pricing**

A key aspect of a HOT lane deployment is the ability to implement dynamic pricing. A communications path into the vehicle offered by IntelliDrive provides greater flexibility for dynamic pricing approaches.

#### ***Opportunities***

Foremost among the opportunities that should be part of a demonstration is the provision of dynamic pricing information to help drivers make decisions about their use of an express lane. A demonstration project should include the use of the

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<sup>14</sup> Texas Transportation Institute, Proc. 2009 Symposium on Mileage-Based User Fees, Austin, TX, April 14-15, 2009, [http://utcm.tamu.edu/mbuf/proceedings/documents/mbuf09\\_proceedings.pdf](http://utcm.tamu.edu/mbuf/proceedings/documents/mbuf09_proceedings.pdf).

secure, high-speed communications channel offered by DSRC to allow drivers to calculate and see their express lane usage fees displayed onboard their vehicle for any destination they select. A demonstration of dynamic pricing capabilities could include the provision of other in-vehicle user account management tools.

It would be desirable for a driver to determine their toll based on current charging rates at points well in advance of the express lane facility, and to be alerted if this toll has changed at any point prior to them entering the express lane, as demand increases or decreases and charging rates change. The effects of changing rates once a driver has entered the facility would need to be a policy decision; however, a demonstration project would provide the opportunity to assess the technical and user response aspects of changing fees during a trip.

The demonstration project could also allow users to interact with their off-board toll account. Access to information such as remaining account balance, in near real-time may influence a driver's decision to use the express lane or not. The use of DSRC or 3G as a means of providing account information into the vehicle could be assessed during the demonstration.

The demonstration could also provide an opportunity to assess other payment mechanisms, such as charging an individual trip to a credit or debit card, or deducting the fee from an onboard electronic purse, instead of debiting an off-board account. The existing FasTrak toll collection system provides cash replenishment accounts for users who desire higher levels of privacy and for the unbanked community. This application may appeal to that user group; although it is reported that there is minimal usage of this option by current FasTrak users. A further reason, however, for addressing this topic in the demonstration is the understanding that it is being discussed in the *IntelliDrive Based Payments Concept of Operations*<sup>15</sup> currently under development for U.S. DOT.

Current express lane deployment plans in the Bay Area call for dynamic message signs prior to the ingress points on the lane. These signs can provide only limited amounts of pricing information, and may require the driver to estimate the fee they will pay based on the information presented. Due to the human factors limitations and dynamic message sign physical limitations (i.e., limited number of characters available on the sign), not all destinations with prices can be displayed. It has been suggested that this may lead to conservative decisions by drivers when approaching the express lane.

IntelliDrive will allow pricing information to be transferred into the vehicle, and alternative prices for different trip options displayed to the driver. In-vehicle systems can also allow more time for the driver to process information and allow the driver to determine the total price for complex trips over multiple express lane segments, which will be particularly important as the express lane network grows throughout the Bay Area.

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<sup>15</sup> At the time of writing this white paper, the referenced Concept of Operations is still under development for U. S. DOT by Booz Allen Hamilton.

The ability to provide information in-vehicle also provides the opportunity to adjust pricing at various decision points for a driver who has already begun a trip on an express lane. It is generally believed that with current approaches, once a driver has committed to a trip on an express lane, their trip price will not change within the corridor, irrespective of the prices that are being charged to new drivers entering the facility. However, this future scenario would provide the opportunity to evaluate the policy options of changing the pricing structure for a driver who has already entered an express lane. New pricing information could be presented to the driver, who could then choose to continue on the express lane or exit back to the general purpose lanes at the next available opportunity.

### ***Challenges***

Presenting decision-oriented information to a driver while they are operating a motor vehicle presents its own set of challenges relating to safety and the driver's cognitive ability to process the information while driving. The driver-vehicle interface (DVI) is technically challenging and potentially expensive. A significant effort in the CICAS-V<sup>16</sup> project was on developing a DVI that was effective but not too distracting. Therefore, although IntelliDrive provides a pathway to get a large amount of information into the vehicle in real-time, the means by which the information is presented and any tasks that must then be performed by the driver must be carefully examined.

### ***Recommendation***

Selected aspects of dynamic pricing form a viable use case for the Phase 2 field test. Other elements are likely to be outside the timing and scope of Phase 2 and are recommended as research projects.

- The ability to pass dynamic pricing information into the vehicle in real-time using an appropriate communications channel such as DSRC or 3G can be evaluated as a use case during the Phase 2 field test. This use case should be conducted under strictly controlled conditions using selected test subjects to address any safety issues associated with the in-vehicle interface. This use case should not be made more generally available to drivers using their vehicles in the HOT lane under normal operating conditions.
- The evaluation of account management tools is a lower priority for the Phase 2 field test. This recommendation is based on the minimal usage of similar features in the existing FasTrak system.
- The development and assessment of an appropriate DVI for this application is beyond the scope of the Phase 2 field test but merits additional research.

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<sup>16</sup> CICAS is a U.S. DOT program to facilitate the implementation of cooperative intersection safety systems that effectively reduce the number of intersection crashes. CICAS-Violation (CICAS-V) is a system that warns the driver via an in-vehicle device when it appears likely that the driver will violate a traffic signal or stop sign. The CICAS-V system is being developed under a partnership agreement with automobile manufacturers.

### 7.1.3 In-Vehicle Account Management

IntelliDrive can provide a communications path between a vehicle and an individual's FasTrak toll account.

#### *Opportunities*

Questions remain regarding an individual's sensitivity to express lane toll pricing. It is possible that a driver will want to consider the available balance in their toll account prior to a decision to use an express lane. This application would allow a driver to obtain a real-time update of their account status in their vehicle before making a decision. This information would not have to wholly reside onboard the vehicle unless there is a desire to anonymize or localize that information. Instead the data could be presented within the vehicle, with the data coming over a secure connection from a back-end accounting system.

The current FasTrak toll collection system in the Bay Area allows users who desire anonymity or do not have a bank account or credit card to establish an account into which they make replenishments in person. It is possible that IntelliDrive could also support the development of an onboard electronic purse that would be used by similar individuals without bank accounts or those wishing to have anonymous transactions. A cash balance could be maintained onboard their vehicle and funds withdrawn at the time of transaction. A variety of technology options could be applied to this use case, including pre-paid cards purchased or replenished at retail outlets in the Bay Area and inserted into an onboard reading device; the driver inputting credit card details via an onboard device; or the use of contactless credit or debit cards interacting with a proximity reader in the vehicle.

#### *Challenges*

Again, issues exist relating to the complexity of tasks that individuals would need to perform while driving.

The concept of maintaining funds in in-vehicle systems would create security challenges, and the need for a broader infrastructure that would allow individuals to load funds onto the device.

#### *Recommendation*

Selected aspects of in-vehicle account management form a viable use case for the Phase 2 field test. Other elements are not recommended for Phase 2.

- The ability to pass account balance information into the vehicle in real-time using an appropriate communications channel such as DSRC or 3G can be evaluated as a use case during the Phase 2 field test. This use case should be conducted under strictly controlled conditions using selected test subjects to address any safety issues associated with the in-vehicle interface. This use case should not be made more generally available to drivers using their vehicles in the express lane under normal operating conditions.

- The evaluation of other account management tools associated with anonymization or onboard purses are a lower priority for the Phase 2 field test. This recommendation is based on the minimal usage of similar features in the existing FasTrak system.

#### **7.1.4 Back-Office Toll Processing**

IntelliDrive technologies could provide a mechanism to reduce or eliminate certain back-office toll transaction processing functions performed by BATA for both the express lane network and ultimately the toll collection system for the bridges.

##### ***Opportunities***

The current FasTrak system requires users to establish an account with BATA and to maintain a balance in that account. As each vehicle passage through a toll plaza is registered by the system the appropriate toll is deducted from the account balance and transferred to the agency as revenue. Once the user's account balance falls below a pre-determined level, the account is replenished; typically through a charge to the user's credit card.

The demonstration would provide an opportunity to assess the potential to eliminate user accounts for toll transactions, and instead initiate a real-time credit card transaction each time a vehicle passes through a tolling zone. The use of the high-bandwidth, secure communications channel associated with onboard DSRC equipment could facilitate the transfer of credit card information to the appropriate financial institution. BATA would then receive payment from the credit card company in a similar manner to other retail transactions.

Mechanisms for the driver to provide their credit card information in-vehicle could include inputting details through a keypad or touch-screen, or the use of emerging contactless credit and debit cards and an onboard proximity reader. The Utah Transit Authority is deploying a system using contactless credit and debit cards for paying bus fares<sup>17</sup>. Transactions are securely encrypted at the onboard reader for subsequent downloading and processing by a third-party provider. In Germany, a new toll collection system for trucks on 12,000 km of the autobahn system called LKW-MAUT collects fees based on mileage driven, number of axles, and emissions category of the vehicle. This system uses an onboard unit linked to GPS, the vehicle odometer, a digital map, and a wireless communications device. The wireless connection is used to authorize payment of the toll<sup>18</sup>.

##### ***Challenges***

Credit card companies typically will not accept the multiple small transactions that would be characteristic of real-time toll collection, instead requiring them to be batched and sent for processing periodically. This may require BATA to

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<sup>17</sup> <http://www.rideuta.com/ridingUTA/amenities/electronicFarefaq.aspx>

<sup>18</sup> <http://www.roadtraffic-technology.com/projects/lkw-maut/>

maintain some appropriate back-office capabilities for this purpose, or use a third party service provider to perform this function.

The in-vehicle toll collection environment also presents challenges for authorizing credit card transactions. BATA is used to a situation in which users maintain funds in an account that is debited as the toll transaction occurs; effectively guaranteeing payment of the toll. In the event that a user passes through a toll plaza without sufficient funds, a toll violation is recognized immediately and automated enforcement is initiated.

In a traditional retail environment, a customer's credit card transaction is authorized at the point of sale. Even if the transaction is then batched and subsequently processed, the retailer is assured payment for the transaction. In the use case envisioned here, there is no simple mechanism to immediately authorize the toll transaction.

However, the New York Metropolitan Transportation Authority allows the use of the MasterCard PayPass, a contactless credit card, for subway fare payments. In this system, PayPass cards are read at the turnstile, and within 300 milliseconds the user is granted access to the system. The user's account is not charged at this point; instead, a preliminary approval verifies only that the card is legitimate. The cardholder's first transaction is always approved, even if their account is not in good standing. The account status is checked later, at which time the system gives the user temporary approval for additional fare purchases that are aggregated into a single transaction — either when their value reaches \$15 or in two weeks' time, whichever comes first. At this point the account status is checked again, and if it is in good standing the user is given another approval, which lasts until the next aggregation.<sup>19</sup>

### ***Recommendation***

Back-office toll processing forms a viable use case for the Phase 2 demonstration. A pilot test should be constructed that demonstrates the ability to process toll transactions using credit and/or debit cards. The test should demonstrate the ability of a driver to provide credit card details through their in-vehicle equipment followed by the secure transfer of the data using DSRC. The pilot test will likely require the participation of an appropriate financial institution, and may require either a batching and processing capability at BATA, or use of a third party service provider.

## **7.1.5 Vehicle Occupancy**

Knowledge of the number of occupants in a vehicle is important to HOV compliance and express lane toll charging. While IntelliDrive technologies may appear to offer solutions to this need, the challenges may be insurmountable at this time.

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<sup>19</sup> Wolfe, Daniel, "MasterCard: Contactless Fares Well," Mobile Banker, August 1, 2008, [http://www.americanbanker.com/issues/173\\_151/-359103-1.html](http://www.americanbanker.com/issues/173_151/-359103-1.html)

### ***Opportunities***

In theory, data on driver and passenger seat occupancy exists onboard the vehicle for use in smart airbag systems. This data, if accessible, could be used to provide an automated count of vehicle occupancy. In the short-term, other technologies, such as roadside multi-band near-infrared (NIR) may be the most promising solution. However, this technology has still not been proven in independent field testing in a HOT lane environment. Testing in the San Diego region is planned for 2010.

### ***Challenges***

For the Phase 2 demonstration, it is unlikely that vehicle occupancy data will be easily accessible through the vehicle's OBDII port since it is used in a critical safety system. However, it may be possible that vehicle manufacturers would be willing to cooperate in a research project in this area.

In the short term, it is likely that vehicle occupancy information will require some form of self-declaration by the driver, such as the use of switchable tags, or an NIR-based technology. Information from these systems could, however, be integrated with other onboard IntelliDrive devices and communicated to roadside equipment.

### ***Recommendation***

Because of the anticipated difficulties with accessing vehicle occupancy data through the vehicle's OBDII port, the vehicle occupancy use case is not being recommended for Phase 2.

The results of testing of multi-band IR technologies in San Diego should be reviewed before considering such systems for the Phase 2 field test.

## **7.1.6 Automated Enforcement**

Automated enforcement is a desirable application in a HOT lane environment. However, it will present both technological and institutional challenges. At the present time, CHP must play a direct role in the enforcement of any HOV or moving violation. Toll violation enforcement and occupancy violation enforcement could continue to be further automated through the use of technology.

### ***Opportunities***

Opportunities and challenges relating to the automated detection of vehicle occupancy are described above in Section 7.1.5 on vehicle occupancy. These directly translate to similar opportunities and challenges that would be experienced in the automated enforcement of HOV violations. Near-term technology uses switchable or self-declaration tags, which provide the opportunity to report occupancy to the roadside infrastructure or to a suitably equipped patrol car. In these cases, the police officer will be required to visually validate the occupancy of self-declared HOVs.

Potentially, vehicle position on the roadway could be tracked, and moving violations involving vehicles crossing the buffer zone could be identified. Lane following systems that track lane markings have been under consideration by some car makers for several years as a safety system to prevent run-off-the-road crashes. These technology approaches may have applicability in this area.

### ***Challenges***

The automated enforcement of either moving or occupancy violations would likely require both policy and legislative changes to be used in California. Technology assessments conducted during the Phase 2 demonstration, however, might be used to support such changes in the longer term.

The use of high-accuracy positioning systems could be considered for identifying vehicle position in the roadway. The Phase 2 demonstration, however, could be used to explore GPS solutions, and assess their ability to provide the necessary positional accuracy levels.

### ***Recommendation***

Automated vehicle occupancy as part of an enforcement strategy appears least amendable to demonstration using IntelliDrive technologies; thus, this use case will not be recommended for the Phase 2 field test. It seems unlikely that onboard sensors to determine occupant counts will be available during the timeframe of the demonstration. It may be possible to consider integrating data from roadside IR readers as part of an enforcement solution. However, we advise deferring decisions on this aspect of the demonstration pending completion of planned trials of this technology in San Diego

However, we recommend that the Phase 2 field test be used as an opportunity to pursue and evaluate positioning system solutions that may provide the level of positional accuracy needed to support a variety of IntelliDrive applications, including buffer zone violations. We recommend that these tests could further the work carried out in the VII POC by conducting tests using the NDGPS and low-cost commercial GPS systems onboard the vehicle, and by seeking to address the identified issues of low positional accuracy under conditions of rapid changes of direction by vehicles traveling on the roadway. If necessary after completing these tests, we further recommend a limited assessment of the approach adopted by Caltrans using INS and Carrier Phase DGPS for snow plow guidance to determine the applicability of the technologies to IntelliDrive HOT lane applications. We recommend that structured technology assessments are performed using selected test vehicles and drivers.

#### **7.1.7 Probe Vehicles**

A probe data service has been considered a central application since the beginning of the VII program. With sufficient penetration of IntelliDrive devices, probe vehicles can provide a detailed picture of prevailing conditions on the roadway network.

### ***Opportunities***

Probe vehicles can be used to measure vehicle speeds and travel times. In turn this information can be used to calculate congestion levels and other performance metrics on various facilities. The data can be used as input to various traveler information and transportation management systems. The information can also be combined with other probe information, such as that gathered by the 511 system from FasTrak-equipped vehicles, to create a richer data set.

Caltrans has recently been testing the use of Bluetooth readers to anonymously determine travel times in both general purpose and HOV lanes. Experiments conducted on SR-99 (with HOV lanes) and I-5 (without HOV lanes) in the Sacramento region indicate a bimodal distribution of travel times on SR-99, with the shorter travel time being close to the free-flow travel time for the segment. This indicates that the HOV lane travel times have been captured. A similar approach could be adopted during the Phase 2 demonstration for the express lanes in the Bay Area.

### ***Challenges***

The quality of the data is directly related to the penetration of probe vehicles on the facilities of interest. However, the use of DSRC locations as specific collection points from which to download data from a vehicle's OBE might be problematic, particularly if the OBE has already "discarded" some data. This approach may not be the most effective for providing reliable data, especially if there is a desire for real-time data. The collection of location and speed data (whether from GPS or cell locators) may be better served by a ubiquitous connection, such as the existing 3G cellular network, or WiMAX or LTE in the future.

### ***Recommendation***

Probe vehicle data collection is a viable use case for the Phase 2 field test. We recommend that the test evaluate alternative communications technologies for gathering probe data. As a minimum these should include DSRC, 3G wireless, and Bluetooth.

## **7.1.8 Traveler Information**

A further benefit of the communications path into the vehicle offered by IntelliDrive is the ability to provide targeted traveler information directly to the driver.

### ***Opportunities***

While many types of traveler information can be accessed by the driver from multiple public and private sources, perhaps the most relevant to express lane deployments in the Bay Area, which could be provided by IntelliDrive, would be information providing real-time travel time differences between the express lane and general purpose lanes. With predictive traffic algorithms, it may also be possible to predict travel time differences in the future. This information could

help drivers with their decision making process on whether they perceive sufficient benefit from using the express lanes.

Accurate travel times rely on the ability to attribute vehicles to specific lanes and to obtain speed and location data from a sufficiently large sample to characterize the traffic stream as a whole. The demonstration will provide an opportunity to assess technological approaches for obtaining vehicle probe data, calculating travel times, and communicating information to and from vehicles. The demonstration could also allow an assessment of blending information from multiple sources to determine if this provides a richer set of travel time data.

As described in Section 7.1.2 above, drivers could also receive dynamic pricing information in their vehicle. This information could relate specifically to their proposed destination and may again support a driver's decisions to use an express lane.

It could also be possible to provide information to current or potential express lane users if an incident occurs in an express lane. This could be valuable in providing specific, targeted information about keeping additional vehicles out of the express lane; returning vehicles from the express lane to the general purpose lanes; or could deal with issues of discounts or refunds.

Information dissemination in the demonstration should recognize that drivers can already receive traveler information in a variety of forms and from multiple sources including the Bay Area's 511 Traveler Information Service. The demonstration provides an opportunity to answer questions both on what information is most relevant to the express lane user (or potential user), and in what ways the IntelliDrive systems implemented for express lane applications can serve as a more effective conduit of information of any type to the driver. In both cases, issues of information presentation and driver distraction must be considered in the demonstration, particularly when comparative travel times of express lanes versus general purpose lanes must be used alongside decisions about cost in a relatively complex cognitive task for the driver.

It should be noted that, at the present time, BATA is not planning to provide comparative travel times for the express lane versus the general purpose lanes.

### ***Challenges***

The ability to provide separate travel times for express lanes and general purpose lanes will depend on the availability of a monitoring infrastructure covering multiple lanes, or a sufficiently detailed set of probe vehicle data using technologies that can localize a probe vehicle to a specific lane.

There is also the question of whether an agency would want to inform drivers if there was no, or only marginal, benefit for using an express lane since this would impact their revenue potential. This may be particularly true once a driver has made the decision to enter the express lane. Driver response to this information, however, could be an important issue to test during the Phase 2 demonstration. This assessment could either confirm or allay agency concerns about presenting travel time information.

### ***Recommendation***

Traveler Information is a viable use case for the Phase 2 field test.

The Phase 2 demonstration should address the provision of relevant information to the express lane user or potential user. Most important among the information that could be provided will be dynamic pricing information, as well as the differences in travel times between the express lanes and the general purpose lanes. The travel time component of the demonstration will have three elements to it: the collection of probe data from vehicles; the processing of data into reliable travel time information; and the dissemination of that information back to the vehicle.

Vehicles equipped with 5.9 GHz toll tags, 915 MHz toll tags or Bluetooth devices could provide probe data for comparative analysis, or to assess the benefits of blending data from multiple sources. Detection equipment could be installed roadside or overhead as appropriate, and used to measure travel times in the general purpose and express lanes.

Analysis techniques could also be assessed during the Phase 2 field test. For example, if a bimodal distribution of travel times is measured, the lower travel time may be assumed to apply to the express lane. Consideration would need to be given to how to analyze the bimodal distribution for travel times when an incident is causing delays in the express lane.

The Phase 2 field test could also evaluate any additional benefits provided by the use of high-accuracy positioning systems to measure vehicle position in the roadway.

Finally, the use of alternative communications paths to the vehicle for the dissemination of travel time and dynamic pricing information could be assessed.

### **7.1.9 Regional and Corridor Traffic Management**

Information that can be gathered from IntelliDrive-equipped vehicles can be directed to the various agencies with operational responsibilities to support a variety of traffic management applications.

#### ***Opportunities***

Vehicles used as probes can provide data that can support active traffic management and corridor management even when they are not operating on an express lane, providing an appropriate infrastructure is available. Probe vehicles may be particularly beneficial on arterial streets where the traffic monitoring infrastructure is typically sparser.

Longer-term research could examine the potential of using information from IntelliDrive-equipped vehicles that have used in-vehicle navigation systems to select destinations that use express lanes when there is an extensive regional network. Such destination selections may provide short-term predictions about express lane (and other facility) usage that could be an input to predictive traffic models or to more complex pricing algorithms.

A future demonstration could assess the role of IntelliDrive systems in supporting this function. In particular, the quality of probe vehicle data could be assessed to supplement or replace traditional vehicle detection stations for monitoring express lane performance in real-time; incident detection; and adjusting pricing levels. The data could also support broader corridor management or regional traffic management strategies, including more holistic approaches to optimization of the entire roadway facility. In all cases, the data gathered during the demonstration could inform the development of appropriate operational algorithms, and help define the interfaces to existing traffic management systems.

### ***Challenges***

These applications will likely rely on some form of vehicle tracking capability that may conflict with IntelliDrive privacy principles.

### ***Recommendation***

The Bay Area Express Lane Network will not be extensive enough in time for the Phase 2 field test; thus, this use case is not recommended.

## **8 TECHNICAL AND OPERATIONAL ISSUES**

During the course of the Phase 2 demonstration, certain technical and operational issues should be specifically addressed. These should be dealt with as part of the system design and development, and during the formal testing and evaluation components of the project.

### **8.1.1 Lane-by-Lane Vehicle Detection**

Lane-level discrimination is an important issue for several applications recommended for the Phase 2 demonstration: express lane toll collection; enforcement of buffer zone violations; probe vehicle monitoring; travel time calculation; and lane performance monitoring all require the ability to locate the vehicle to a specific travel lane. Other programs being discussed at the national level, such as VMT (vehicle miles traveled) fees to replace or supplement diminishing gas tax revenues for highways, might also benefit from lane-level vehicle detection to enable more complex pricing algorithms.

Current toll collection systems typically locate antennas on structures above the roadway and focus the antenna read zone on a particular lane to localize a vehicle. The localization is further refined through software using algorithms that identify the multiple reads associated with lane-straddling vehicles. Kapsch has described a similar approach for its DSRC toll collection solution but with the use of only a single antenna over the HOT lane. Independent assessment of this approach is not yet available.

During the demonstration, it would be desirable to assess the ability of DSRC equipment to achieve similar lane discrimination without an overhead structure; instead using roadside mounted equipment. This may require the use of supplementary GPS devices onboard the vehicles that can provide lane level accuracy. The testing of roadside mounted DSRC equipment could also assess the

ability to establish multiple toll transaction points with a single antenna zone, and the effects of closely-spaced DSRC equipment with overlapping antenna zones.

The particular low-cost commercial GPS equipment used in the VII POC test in Michigan was not sufficiently accurate to provide lane-level positional accuracy (generally considered to be a 95% CEP of less than 1 meter for appropriate IntelliDrive applications). However, other efforts are ongoing to demonstrate high-accuracy GPS capabilities for transportation applications, including work performed by Caltrans on snow plows that is described earlier. The Caltrans test, however, used equipment with a high on-vehicle unit cost.

It is recommended that further work could be carried out that seeks to address the issues experienced during the VII POC. If necessary, a limited assessment of the approach adopted by Caltrans could be conducted during the Phase 2 field test. One or both of these system approaches could be used to support or enhance the assessment of applications that require accurate vehicle positions. Progress to develop other affordable systems with high levels of positioning accuracy should also continue to be monitored.

### **8.1.2 In-Vehicle Driver Displays**

As noted earlier, the complexity of in-vehicle displays and the nature of the tasks that must be performed by the driver to make decisions on whether to use the express lane create the potential for distractions from the principal driving task and, therefore, may compromise driver safety. It is recommended that the demonstration included consideration of the human factors requirements for the system. It is believed that much can be learned from the work of the VIIC on the CICAS-V project.

### **8.1.3 Driver and Vehicle Privacy**

During the course of the demonstration it will be necessary to collect data for travel time measurements that will uniquely identify vehicles and their locations as they travel on the network. MTC currently performs a similar function for its 511 Driving Times<sup>SM</sup> service based on FasTrak toll tags. The tag users' consent is secured through their FasTrak license agreement. In the 511 project, encryption software masks each tag ID before any other processing is done to ensure that the toll tags are treated anonymously. The encrypted tag IDs are retained for no longer than twenty-four hours and then discarded. No historical database of the encrypted IDs is maintained beyond that time period.

## **9 ANALYSIS OF POTENTIAL HOT LANE CORRIDORS**

This section of the white paper discusses potential demonstration locations for Phase 2. In general, based only on the timing of implementation, two corridors are candidates for the demonstration phase: the I-880/SR 237 Express Lane Connector, and the I-680 Corridor. A third corridor, the I-580 eastbound express lanes, is also described, although its deployment schedule will likely place it beyond the Phase 2 demonstration project. These projects are described briefly below.

### 9.1.1 I-880/SR 237 Express Lane Connector

The Santa Clara Valley Transportation Authority (VTA) will convert existing HOV-to-HOV direct connector lanes to express lane connectors at the I-880/SR 237 interchange. HOVs will continue to use the express lane connectors for free, while LOVs will pay a toll. Toll rates will be set dynamically to maintain free-flow conditions on the express lanes.

The express lanes will use separated ingress and egress lanes to prevent weaving, and solid lines as a buffer zone between the express lanes and the general purpose lanes. However, the express lane is physically separated from the general purpose lanes for much of its length as it runs on the elevated direct connector roadway segment. Beyond the direct connector, the express lane will revert to an HOV-only lane and HOT vehicles will be required to exit and return to the general purpose lanes. Operational details of exiting appear to be still under development; although it seems that HOT vehicles will be prevented from exiting onto Zanker Road, but will have returned to the general purpose lanes before the exit to First Street.

In common with other express lane implementations in the region, motorists will receive express lane toll pricing information from overhead changeable message signs in advance of the express lane. The use of toll tags in the express lane appears to be in a state of flux at the present time. Published information indicates that all LOVs that wish to use the express lanes will be equipped with a toll tag compatible with the existing FasTrak system, while HOVs will need to cover their toll tag before entering the express lane to prevent a toll charge. A toll transaction will be initiated when a non-HOV vehicle enters the express lane; processing of the toll is a back office function that will use existing systems.

Toll violations will be handled electronically, while occupancy violations and moving violations will be handled in the traditional manner by CHP officers.

This facility should be operational in 2010, although it is possible that this may be delayed until 2011.

#### ***Demonstration Considerations***

It has been suggested that there may not be an overhead structure or power downstream of the separated direct connector section of the facility. This could limit options for equipment installation or placement during the demonstration.

The relatively small size of the facility, however, could be beneficial. This may provide an opportunity to assess the effectiveness of placing a single DSRC roadside device on the facility, and test the ability to accurately tune the antenna pattern to support various applications.

It is very likely that the facility will be available in an appropriate timeframe for the proposed IntelliDrive demonstration project.

### 9.1.2 I-680 Express Lane

This facility is located on a 14-mile section of southbound I-680 between SR 84 and SR 237. Approximately 80 percent of the facility is located in Alameda County, with the remainder in Santa Clara County. The project is being undertaken by a Joint Powers Authority comprising the Alameda County Congestion Management Agency (which serves as project administrator), the Alameda County Transportation Improvement Agency, and the Santa Clara Valley Transportation Authority. In common with the previous project, HOVs will use the express lane for free, while LOVs will pay a toll. Toll rates will be set dynamically to maintain free-flow conditions on the express lanes.

The express lanes will use transition lanes for access, and solid lines as a buffer zone between the express lanes and the general purpose lanes. This facility will comprise three entrance points to the express lanes (south of SR 84; south of north Mission (SR 238); and south of Auto Mall Parkway), and three exit points (north of south Mission; north of Calaveras Boulevard (SR 237); and south of Calaveras Boulevard). The final two exit points are closely-spaced (approximately eight-tenths of a mile) and will be charged at the same rate.

The operational approaches for toll collection and enforcement will be the same as those described for the I-880/SR 237 express lane connector, with similar issues emerging.

Construction is underway on this facility, and design of the toll collection system is proceeding. The facility is intended to be open around September 2010.

#### *Demonstration Considerations*

The length of this facility provides greater opportunity to test a variety of IntelliDrive applications. Overhead structures and power at the various entrance/exit points also provide flexibility for installing various configurations of equipment. A T1 connection and wireless communications will be available at each toll zone and may also be beneficial if they can be used during the demonstration. Vehicle detection equipment (loops and redundant roadside RTMS devices), which will already exist in the corridor, may be useful for establishing ground truth or providing additional traffic data during the demonstration.

Since there will be only two express lane usage prices at any time (the last two exits are priced the same), this will limit the ability to measure user response to the flexibility of in-vehicle pricing information. However, the spacing of the final two exits may be beneficial for assessing the effects of closely spaced or, possibly, overlapping read zones for DSRC equipment.

It may not be possible to investigate sensitivity to lane changes in some applications given the relatively short length of the ingress/egress point. Since there are no physical barriers between the express lanes and general purpose lanes, it would be possible to explore this topic by violating the buffer zone. Such tests would need to be coordinated with CHP and conducted during light traffic periods.

An analysis of gathering travel times for both the express lanes and the general purpose lanes will require a sufficient penetration of equipped vehicles in both types of lanes. This may need to be conducted as a controlled test and may need to utilize overhead structures for equipment placement in order to assure sufficient accuracy in vehicle position measurement.

The timing of the I-680 project would appear to provide the lowest risk in terms of meeting the schedule requirements of the IntelliDrive demonstration.

### **9.1.3 I-580 Eastbound Express Lanes**

The Alameda County Congestion Management Agency (ACCMA), in cooperation with Caltrans, is currently undertaking construction of an eastbound HOV lane along I-580 from Hacienda Drive to east of Greenville Road. Work began in September 2008, and the HOV lane is planned to open in two phases: the first in late 2009 and the second in 2011.

In parallel, ACCMA and Caltrans are preparing an environmental review for the conversion of the new HOV lane to an express lane. The review is assessing the feasibility of providing two express lanes in the eastbound direction. The environmental review is scheduled to be completed in 2010. If feasible, the new HOV lanes would be converted to express lanes at the completion of construction in 2011.

#### ***Demonstration Considerations***

The timing of the I-580 eastbound express lanes does not appear to be consistent with the needs of the Phase 2 demonstration. Therefore, this corridor is not recommended for further consideration at the present time.

## **9.2 Corridor Recommendation**

While the layout of the I-880/SR 237 Express Lane Connector offers some interesting testing opportunities, it is not recommended for the Phase 2 field tests. The length, configuration, and availability of roadside and overhead infrastructure appear to make the I-680 Express Lane a more desirable location for testing. Based on this analysis, it is recommended to use the I-680 corridor for the Phase 2 demonstration.

## **10 ANALYSIS OF FLEET OPTIONS**

Testing of the IntelliDrive express lane use cases in Phase 2 will require the availability of test fleets. Specific requirements for the test fleets, including requirements relating to individual vehicles and drivers, should be developed as part of the development of demonstration evaluation and test plans. The number of vehicles needed for testing a particular use case, for example, will generally be determined by the statistical confidence and accuracy desired for the resulting performance measurements.

Testing that considers particular vehicle or driver characteristics, operational behaviors, or technology configurations will typically influence the number of test

vehicles required, as well as the manner in which the tests should be performed. For example, a test that measures the long-term performance of a new system under normal roadway operating conditions or a test to gauge users' long-term response to a system may be best served by installing the devices in commuters' cars for extended periods. By contrast, a test that is intended to evaluate the limits of a technology, such as the effects of a very specific lane position or lane straddling scenario may require the use of professional testers conducting a highly structured test over a limited period. Other factors, such as the nature of the in-vehicle equipment (prototype or production), or the type and format of data to be collected during the test, will also affect the decision to use regular commuters or professional drivers in a particular situation. In all cases, consideration must be given to the need for appropriate insurance and the handling of liability by the testing organization and the agencies involved. Recent examples of tolling and IntelliDrive test fleets may be instructive.

For the VII POC in 2008, the VII Consortium (VII-C) provided 25 dedicated vehicles that were equipped with an OBE subsystem and active dual GPS/DSRC antennas. The vehicles were used for a series of structured tests covering quantitative assessments of specific functional services in the system, including DSRC communications, positioning, security, and vehicle interface, as well as an evaluation of selected system applications. Individual test cases typically used from one to three vehicles, depending on the nature of the test. Test vehicles were operated by professional drivers from Roush Industries<sup>20</sup>.

Kapsch recently performed a set of tests of their multi-lane free flow tolling system at a trial facility operating on the E-470 tollway near Denver, Colorado. In this trial they tested their 5.9 GHz DSRC toll tags and detectors, vehicle detection and classification, and automatic license plate recognition solutions. Each application was characterized by different performance measures, but used a common fleet of test vehicles. Because the tests were focused on specific technical measures—for example, tolling transaction performance rate—a relatively small fleet of 27 vehicles operating over a few weeks was needed. Test vehicles and drivers were openly solicited from the general public through a Craigslist ([www.craigslist.org](http://www.craigslist.org)) posting.

The VII California Tolling Tests were performed as an extension of the larger set of VII POC tests, specifically to demonstrate integration with an existing tolling infrastructure and revenue collection system. These tests evaluated specific technical capabilities for basic functionality and were not driven by the need for conclusive statistics. Only two agency vehicles were used in this testing.

Testing of the driver behaviors and experiences typically requires a more sophisticated testing configuration and test subject selection process. The need to evaluate or isolate the impacts of test subject demographics can significantly increase the subject populations, and the length of subject observations needs to account for learning and experience time intervals. Testing the usability of driver-

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<sup>20</sup> U.S. DOT Research and Innovative Technologies Administration, "VII Proof of Concept Results and Findings Summary – Vehicle. Final Report." Prepared by the VII Consortium, May 2009.

vehicle and driver-device interfaces can extend to in-vehicle video recording and analysis in dedicated test vehicles. Testing of this type may be desirable for evaluating, for example, driver compliance in using self-declaration switchable toll tags, driver response to traveler information interfaces, or driver decisions driven by dynamic pricing and in-vehicle account management.

For the use cases recommended for Phase 2, it is likely that a blend of equipment, vehicle, and driver alternatives will be needed. The sophistication and cost of some technologies to be tested will constrain the number of units that can be obtained. This may be mitigated to some extent by research and development partnerships with system vendors. Other recent studies have had success in soliciting drivers and their vehicles from among the public, and this may be a prudent option for those tests where the number of subjects and volume of test data is a primary consideration. Either agency vehicles and drivers, or leased vehicles and professional drivers are reasonable candidates for tests of particular technological capabilities which may have high cost or security constraints. Recommendations for each use case are provided in section 11.

## **11 PHASE 2 RECOMMENDATION**

IntelliDrive technologies appear to offer significant potential for supporting or enhancing typical HOT lane operations, and specifically for particular needs of the express lane network in the Bay Area. This section recommends the most viable and logical use cases that could be demonstrated in the Bay Area during Phase 2 of this project. As appropriate, the use cases include recommended wireless communication method(s) and any other necessary enabling technologies. The requirements for test vehicle fleets are also discussed. A recommendation is provided for a suitable test corridor, and recommended schedule for Phase 2 is presented.

### ***11.1 Recommended Use Case # 1 – Toll Collection***

Toll collection is a viable use case for the Phase 2 field test. It is recommended that the following test scenarios are explored:

- Use of 5.9 GHz DSRC equipment mounted over the express lane alone to determine the ability of the technology to differentiate vehicle location in a multi-lane situation. This test should be configured in a manner that explores the possibility of reliable toll collection in a roadway layout that provides continuous access to the HOT lane;
- Use of dual-mode 5.9 GHz/915 MHz readers and tags with the 5.9 GHz/915 MHz equipment mounted on the existing overhead structure alongside the existing 915 MHz equipment to evaluate the effectiveness of this technology and its compatibility with existing FasTrak operations;
- Use of 5.9 GHz DSRC equipment mounted on the side of the road, potentially in conjunction with high-accuracy positioning equipment onboard the vehicle, to evaluate the capability of lane level detection

without the need for an overhead structure, as well as the ability to accurately collect tolls.

We recommend two groups of drivers as subjects for this test. The first group would be recruited commuters (say 50 - 100 regular users of the corridor with a willingness to use the express lane). This group would be used as a source of data on the general operating characteristics of the system and the users' response to the system. These tests would be conducted over an extended period.

The second group would comprise a limited number of professional drivers (say 2-5) who would conduct structured tests to measure the limits of system performance. These tests would be conducted over a specified, limited period.

We further recommend that this use case be used as an opportunity to pursue and evaluate positioning system solutions that may provide the level of positional accuracy needed both for the toll collection application and to support a variety of other IntelliDrive applications, including buffer zone violations.

- We recommend that these tests will first further the work carried out in the VII POC by conducting tests using the NDGPS and low-cost commercial GPS systems onboard the vehicle, and will seek to address the identified issues of low positional accuracy under conditions of rapid changes of direction by vehicles traveling on the roadway.
- If necessary after completing the tests that continue the work of the VII POC, we further recommend a limited assessment of the approach adopted by Caltrans using INS and Carrier Phase DGPS for snow plow guidance to determine the applicability of the technologies to IntelliDrive HOT lane applications.

We recommend that the positioning system testing should comprise structured technology assessments, performed using a limited number of selected test vehicles and drivers. Two equipped vehicles could be used to further the work of the VII POC, with an additional two vehicles equipped with INS and Carrier Phase DGPS to continue the Caltrans testing, if necessary. For the latter assessment, one to two base stations would be required depending on the desire to entirely or partially cover the corridor.

## ***11.2 Recommended Use Case # 2 – Back Office Toll Processing***

Back-office toll processing forms a viable use case for the Phase 2 demonstration. We recommend that a pilot test should be constructed that demonstrates the ability to process toll transactions using credit and/or debit cards. The test should demonstrate the ability of driver to provide credit card details through their in-vehicle equipment and secure communications of the information using DSRC. The pilot test will require the participation of an appropriate financial institution, and may require either the necessary batching and processing capability at BATA, or use of a third party service provider.

We recommend that the test should include the use of contactless credit or debit cards, and an onboard proximity reader, such as those being used by transit

agencies in New York and Utah, as well as the ability for drivers to input credit card details through an in-vehicle keypad or touch screen associated with an onboard IntelliDrive device. This will create the opportunity to assess the availability and technical feasibility of a variety of in-vehicle equipment configurations.

We recommend that the equipment is installed in a limited number of vehicles (say 2 – 5 for each equipment configuration), and that the testing is conducted in a structured manner by professional subjects.

### ***11.3 Recommended Use Case # 3 – Traveler Information***

Traveler information is recommended as a viable use case for the Phase 2 demonstration. We recommend that this use case comprise several aspects of traveler information uniquely associated with express lane operations or facilitated by the availability of IntelliDrive technologies. The Phase 2 demonstration should address the provision of relevant information to the express lane user or potential user. Most important among the information that could be provided are dynamic pricing information, FasTrak account balance information, and travel time comparison between the express lanes and the general purpose lanes.

- Selected aspects of dynamic pricing form a viable use case for the Phase 2 field test.

The ability to pass dynamic pricing information into the vehicle in real-time using an appropriate communications channel, including DSRC and 3G wireless, can be evaluated as a use case during the Phase 2 field test, and, as a minimum, prototype equipment for presenting the information to the driver. This use case should be conducted under strictly controlled conditions using professional test subjects to address any safety issues associated with the prototype in-vehicle interface. This use case should not be made more generally available to drivers using their vehicles in the express lane under normal operating conditions unless a suitable production driver-vehicle interface is available for the Phase 2 demonstration.

A limited number of test vehicles should be used for this test; say 2 – 5 vehicles for each communications alternative.

- Selected aspects of in-vehicle account management form a viable use case for the Phase 2 field test.

The ability to pass FasTrak account balance information into the vehicle in real-time using an appropriate communications channel, including DSRC and 3G wireless, can be evaluated as a use case during the Phase 2 field test, and, as a minimum, prototype equipment for presenting the information to the driver. This use case should be conducted under strictly controlled conditions using professional test subjects to address any safety issues associated with the prototype in-vehicle interface. This use case

should not be made more generally available to drivers using their vehicles in the express lane under normal operating conditions unless a suitable production driver-vehicle interface is available for the Phase 2 demonstration.

A limited number of test vehicles should be used for this test; say 2 – 5 vehicles for each communications alternative.

- We recommend a travel time information component of the demonstration that will comprise three elements: the collection of probe data from vehicles; the processing of data into reliable travel time information; and the dissemination of that information back to the vehicle.

Vehicles equipped with 5.9 GHz DSRC, 915 MHz toll tags or Bluetooth devices should provide probe data for comparative analysis. The test should also assess the benefits of fusing data from multiple sources. Appropriate detection equipment should be installed roadside or overhead as appropriate, and used to measure travel times in the general purpose and express lanes.

The development of appropriate data analysis techniques should also be undertaken and validated during the Phase 2 field test. For example, if a bimodal distribution of travel times is measured, the lower travel time may be assumed to apply to the express lane. However, consideration would need to be given to how to analyze the bimodal distribution for travel times when an incident is causing delays in the express lane.

The Phase 2 field test should also evaluate if any additional benefits to the calculation of travel times in express and general purpose lanes are provided by the use of high-accuracy positioning systems to measure vehicle position in the roadway.

Finally, the use of alternative communications paths to the vehicle for the dissemination of travel time information should be assessed. As a minimum these should include DSRC and 3G wireless.

#### ***11.4 Recommended Express Lane Corridor***

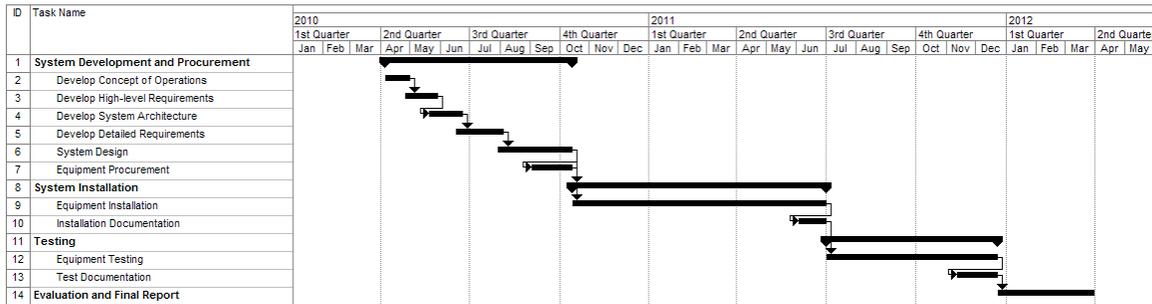
It is recommended to use the I-680 corridor for the Phase 2 demonstration. The length and configuration of the express lane corridor, as well as the availability of roadside and overhead infrastructure appear to make the I-680 Express Lane a more desirable location for testing.

#### ***11.5 Recommended Schedule***

To a certain extent, the overall schedule for the Phase 2 demonstration will be driven by the agreement between U.S. DOT and MTC that defines milestones for the project within the Urban Partnership Program. Recognizing these constraints, a recommended schedule is presented in Figure 4 below.

The schedule assumes that the project will adopt a systems engineering process starting with the development of a concept of operations, followed by

requirements development, design, and system development, prior to the implementation of the demonstration itself.



**Figure 4: Recommended Phase 2 Demonstration Project Schedule**

## 12 PROGNOSIS FOR INTELLIDRIVE<sup>SM</sup> HOT LANE OPERATIONS

The purpose of the Phase 2 demonstration project is to establish the technical, operational, and institutional viability of some or all of the IntelliDrive technologies described in this white paper for supporting HOT lane applications. Much will be learned from the demonstration that will inform future deployment decisions in the Bay Area, as well as provide input and direction to the national IntelliDrive agenda.

However, based on the development of this white paper we believe that there is strong potential for commercial deployment of IntelliDrive for HOT lane operations at the conclusion of Phase 2. We believe that there are multiple viable applications of IntelliDrive technologies for HOT lane operations that can be developed. This can alleviate the risk of stalling program deployment if one specific application is found not to be feasible. We also believe that there are opportunities for continuing development and enhancement for the system in the future (for example, as technologies improve and automated enforcement becomes practical; or as the initially deployed system develops to support broader regional traffic management applications). This inevitably creates greater commercial market interest in the development and deployment of the system.

In particular, we believe that the tolling aspects of the project have the potential to generate strong vendor interest. The anticipated extensive regional express lane network will likely create strong demand for both in-vehicle devices and roadside equipment over many years. This will attract the vendor community to the project. If there is also some potential of a transition from the existing FasTrak devices to new IntelliDrive devices for all toll collection in the Bay Area, even greater interest can be expected.

## **APPENDIX A - STAKEHOLDERS INTERVIEWED**

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Albert Yee, Metropolitan Transportation Commission

Beth Zelinski, Bay Area Toll Authority

Casey Emoto, Santa Clara Valley Transportation Authority

Charles Price, California Department of Transportation, District 4

David Kobayashi, Santa Clara Valley Transportation Authority

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Eric Rozenoff, California Highway Patrol

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Murali Ramanujam, Santa Clara Valley Transportation Authority

Rod McMillan, Bay Area Toll Authority

Sean Nozzari, California Department of Transportation, District 4